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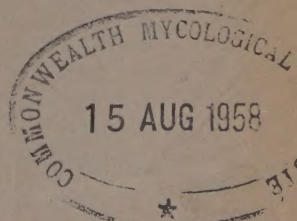
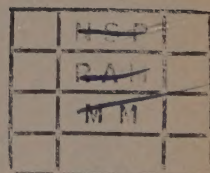
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EFFECT OF STOCK-SCION INTERRELATIONSHIPS ON THE TRANSPORT OF ^{32}P AND ^{45}Ca IN THE APPLE*

By M. J. BUKOVAC, S. H. WITTEW and H. B. TUKEY
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OVER the years much information has been accumulated regarding the dwarfing effect of rootstock upon scion. However, no factor or factors have thus far been identified which adequately explain the dwarfing response from certain rootstocks. Furthermore, few data are available relating nutrient transport to vigour. The study presented in this paper deals with the transport of ^{32}P and ^{45}Ca by several apple rootstocks.

Daniel and Thomas (1902) demonstrated that the roots of a grafted bean plant (*Phaseolus vulgaris* var. Belgique/Soissons) absorbed less nutrients from a culture medium than either the non-grafted Belgique or Soissons. Roach (1931), working with Lane's Prince Albert apple scions budded on M.IX and M.XII, found by spectrographic analysis that, of the following twenty-one elements, potassium, calcium, magnesium, sodium, phosphorus, iron, aluminium, manganese, barium, strontium, lithium, copper, lead, titanium, vanadium, silicon, nickel, chromium, tin, molybdenum and silver, all were absorbed from the soil and transported to the scions with the exception of lead and molybdenum. Lead was restricted to the roots in all cases, while molybdenum occurred only in the rootstock of Lane's/M.IX and was not detected in the scion or rootstock of Lane's/M.XII. The physiological significance of molybdenum absorption and transport has not been established.

Chemical analysis of the terminal shoots of two apple varieties grown on nine Malling rootstocks showed significant differences in chemical constituents as influenced by rootstock (Warne and Wallace, 1935). The rootstock effect on growth, however, could not be explained on the basis of chemical composition. Using potassium bromide to measure absorption, Berry (1939) suggested that the vigour of the rootstocks may be related to their capacity for absorbing mineral solutes.

Differential absorption and transport of nutrients or a combination of the two processes as contributing factors in the stock-scion interrelationship have been suggested by Swarbrick *et al.* (1946). That nutrient intensity may play a rôle in stock vigour was recently demonstrated by Ruck and Bolas (1956). They found that Crab C was 73 per cent. more vigorous than M.IX when grown in sand cultures with 5 p.p.m. nitrogen, whereas with 200 p.p.m. of nitrogen the relative difference was only 12 per cent. Ruck and Bolas further suggested that, in the vigorous rootstock (Crab C), translocation was relatively more efficient at the lower than at the higher nitrogen level.

* Journal article No. 2097 from the Michigan Agricultural Experiment Station, East Lansing, Michigan; condensed from a thesis submitted by M.J.B. to the School of Graduate Studies, Michigan State University, in partial fulfilment for the degree of Doctor of Philosophy.

GENERAL METHODS.

Experimental plants with varying degrees of vigour were prepared by "T" budding McIntosh Red in August 1954 on M.IX, M.VII, M.XVI and Delicious seedling rootstocks. In the spring of 1955 the plants were placed in glass jars (3.5 litres) containing half-strength Hoagland solution (Hoagland and Arnon, 1950), which in turn were set in tanks maintained at $13^{\circ} \pm 1^{\circ}$ C. by a circulating water bath and thermostatically controlled refrigerating and heating units (Fig. 1). The design of the tanks has been described in detail by Roberts (1953). The nutrient solutions were vigorously aerated from a central air supply which was filtered and distributed to each jar through aerating stones (Wards Natural Science Establishment, Rochester, New York). At the time of bud break the half-strength Hoagland solution was replaced with full-strength and thereafter changed weekly.

Radiophosphorus (^{32}P) as ortho-phosphoric acid and radiocalcium (^{45}Ca) as calcium chloride were obtained from the Oak Ridge National Laboratory, Oak Ridge, Tennessee. Optimum concentrations and pH of the treating solutions were determined from preliminary experiments, and short time (24 to 144 hours) intervals were used to study transport.

Radiocalcium determinations were made by ashing plant samples in a muffle furnace at 550° C. for 12 hours and the ash was dissolved in 5 ml. of 2N hydrochloric acid and made up to volume (25 ml.). One or five millilitre aliquots were then transferred to Coor milk ashing capsules, evaporated to an infinitely thin film ("zero thickness") and counted with an end-window G-M tube and a Nuclear Instrument and Chemical Corporation Model 172 scaling unit. For radiophosphorus determinations, samples were ashed according to the procedure outlined by A.O.A.C. (1950) and counted as described for radiocalcium above.

A randomized experimental design of three single-plant replicates was used and estimates of variability were by analysis of variance (Snedecor, 1946).

EXPERIMENTAL RESULTS.

Transport of root-absorbed ^{32}P by rooted layers.

Uniform rooted layers of M.IX, M.VII and M.XVI were started in solution cultures on 24th March 1955. Three days after the initiation of growth, all but one of the vigorous shoots were removed. On 27th April, 0.5 microcurie (μc) of ^{32}P was added per milligram of ^{31}P in the nutrient solution.

The new shoots and roots were harvested 24, 48, and 96 hours after ^{32}P had been added to the root medium, and the dry weights determined. The ^{32}P transported to the new shoot was then determined and expressed as counts per minute per gram dry weight of shoot per milligram of total root.

The data indicated that increasing quantities of ^{32}P were transported to the shoots of M.IX, M.VII and M.XVI with time (Fig. 2). The greatest quantity of ^{32}P was transported by the vigorous layer M.XVI, the least by the dwarfing layer M.IX, and an intermediate amount by the semi-dwarf layer M.VII. No explanation is apparent as to why the shoot of M.VII contained less ^{32}P at 24 hours than the more dwarfing M.IX.

Transport of root-absorbed ^{32}P and ^{45}Ca to the bud union and scion.

Uniform plants (McIntosh on M.VII, M.IX, M.XVI and Delicious seedlings), budded in August, were removed from the nursery storage cellar on 1st February 1955

and the part of the rootstock above the newly placed bud was removed. The plants were grown in solution cultures as described earlier.

Six weeks after scion growth began, one microcurie of ^{32}P or 0.5 microcurie of ^{45}Ca was added per milligram of ^{31}P or ^{40}Ca , respectively, in the nutrient solution. The plants were harvested 24, 48 and 96 hours after the addition of ^{32}P and 48, 96 and 144 hours after the addition of ^{45}Ca to the root medium and separated as follows: (a) scion, (b) five-centimetre stem segment containing the bud union, (c) rootstock-stem below the bud union, and (d) roots.

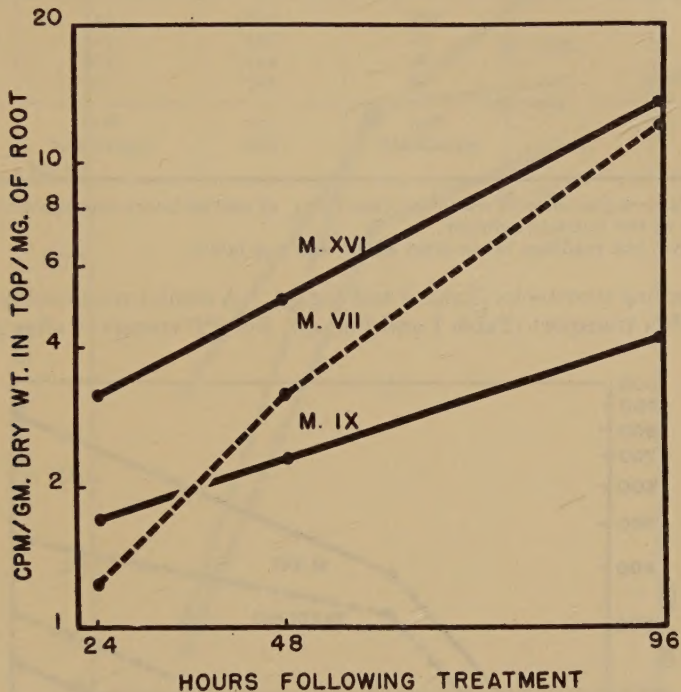


FIG. 2.

Transport of root-absorbed radiophosphorus (^{32}P , counts per minute per gm. dry wt. of top per mg. of root) to the tops of rooted layers of M.IX, M.VII and M.XVI, 24, 48 and 96 hours following the addition of the isotope to the root medium.

At the times of harvest no significant differences could be detected in the root-absorbed ^{32}P or ^{45}Ca recovered in the bud union segments formed by McIntosh on all four of the rootstocks used (Table I). Extreme variability was evident in these samples.

A clear distinction, however, was apparent between the dwarfing (M.IX and M.VII) and vigorous (M.XVI and Delicious seedling) rootstocks in their ability to translocate both ^{32}P and ^{45}Ca to the scions. The least amount of root-absorbed ^{32}P was transported to the McIntosh scion on M.IX, with an intermediate value for McIntosh/M.VII and the greatest quantity to the McIntosh scion on M.XVI and

TABLE I.

Radioactivity (cpm/gm. dry weight) in bud unions and scions of McIntosh on M.IX, M.VII, M.XVI and Delicious seedling rootstocks following root-absorption of ^{32}P and ^{45}Ca .

McIntosh scions on :	Root-absorbed ^{32}P recovered		Root-absorbed ^{45}Ca recovered	
	Bud unions*	Scions*	Bud unions†	Scions†
M.IX	106	148	447	621
M.VII	78	194	518	1,187
M.XVI	39	457	322	2,028
Delicious seedling	8	297	—	—
L.S.D. 5%	Not significant	77	Not significant	1,020
L.S.D. 1%	significant	106	significant	1,395

* Each value is the mean of readings taken at 24, 48 and 96 hours subsequent to the addition of the isotope to the nutrient solution.

† As above, but readings taken after 48, 96 and 144 hours.

Delicious seedling rootstocks (Table I and Fig. 3). A similar relationship was demonstrated for ^{45}Ca transport (Table I and Fig. 4). For ^{32}P transport after 24 hours, the

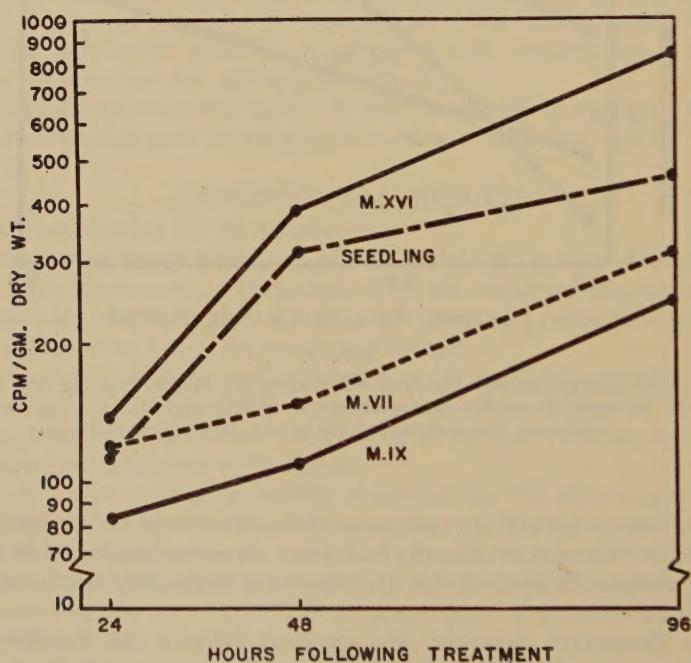


FIG. 3.

Transport of root-absorbed radiophosphorus (^{32}P , cpm/gm. dry wt.) to the McIntosh scions on M.IX, M.VII, M.XVI and Delicious seedling apple rootstocks, 24, 48 and 96 hours, following the addition of ^{32}P to the root medium.

most vigorous combination (McIntosh/M.XVI) differed from the most dwarfing (McIntosh/M.IX) by less than 100 counts per minute (cpm). This difference was greatly accentuated at 48 and 96 hours. The ^{32}P and ^{45}Ca transport curves (Figs. 3 and 4) for the dwarfing stocks (M.IX and M.VII) were almost parallel, as were the ^{32}P transport curves (Fig. 3) for the vigorous stocks (M.XVI and Delicious seedling).

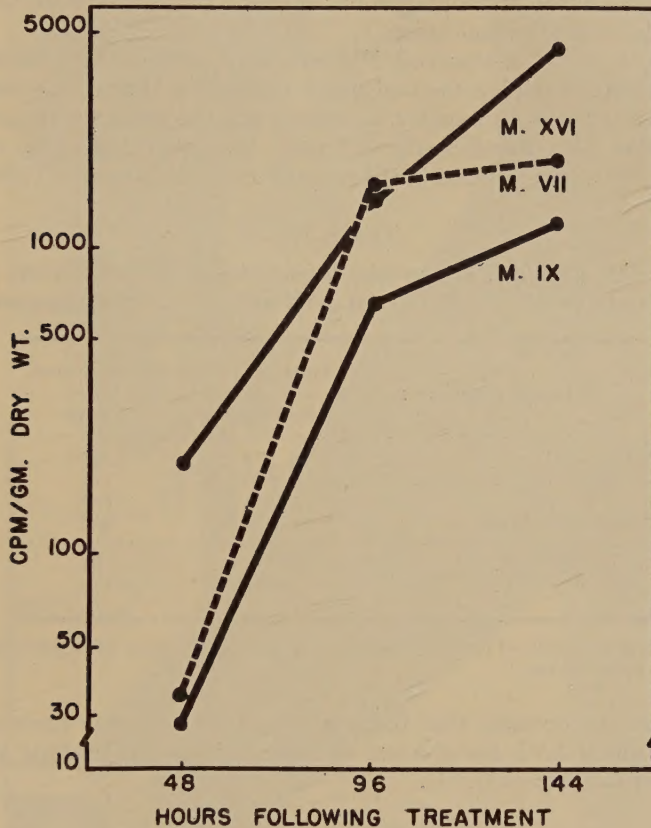


FIG. 4.

Transport of root-absorbed radiocalcium (^{45}Ca , cpm/gm. dry wt.) to the McIntosh scions on M.IX, M.VII and M.XVI apple rootstocks, 48, 96 and 144 hours following the addition of ^{45}Ca to the root medium.

Transport of foliar-absorbed ^{32}P to the bud union and roots.

Transport of foliar-absorbed ^{32}P was next studied, using plant material and cultural methods as previously described. Radiophosphorus (^{32}P) was added to a solution of ortho-phosphoric acid (0.2 per cent.) and the pH adjusted to 2.0 with potassium hydroxide. Fifteen drops (0.01 ml. per drop) of the isotopic treating solution (30 $\mu\text{C}/\text{ml.}$) were applied to the upper surfaces of the fourth and fifth leaves of the scion by means of a tuberculin syringe with a No. 27 stainless steel needle.

Plants were harvested 24, 48 and 96 hours after treatment, and separated as follows: (a) treated leaves, (b) scion above the treated leaves, (c) scion below the treated leaves, (d) five-centimetre phloem segment containing the bud union, and (e) roots.

Radioactive analysis of the scion above the treated leaves showed no significant differences irrespective of rootstock. Likewise there was no significant difference between rootstocks in the accumulation of ^{32}P in the region below the treated leaves and immediately above the bud union.

The quantity of foliar-absorbed ^{32}P recovered in the bark (phloem, cortex, epidermis) segment containing the bud union formed by McIntosh scions on M.IX, M.VII, M.XVI and Delicious seedling rootstocks did not differ significantly between rootstocks (Table II). Significantly different quantities (cpm/gm. dry wt.) of foliar-absorbed ^{32}P were recovered in the roots of the various plants (Table II).

TABLE II.

Foliar-absorbed ^{32}P (cpm/gm. dry weight) transported to the bud unions and roots of McIntosh scions on M.IX, M.VII, M.XVI and Delicious seedling rootstocks.

McIntosh scions on :	Foliar-absorbed ^{32}P * recovered	
	Bud unions	Roots
M.IX	514	151
M.VII	688	224
M.XVI	594	170
Delicious seedling	675	308
L.S.D. 5%	Not	82
L.S.D. 1%	significant	113

* Each value is the mean of readings taken at 24, 48 and 96 hours subsequent to the application of ^{32}P to the scion leaves.

Radioactive analysis revealed that the least amount of ^{32}P was transported to the roots of M.IX and M.XVI, the greatest to those of Delicious seedling and an intermediate amount to those of M.VII.

DISCUSSION.

It is evident from the data presented herein that a close relationship exists between the transport rates of radiophosphorus and calcium from solution cultures and the vigour observed in McIntosh scions on M.IX, M.VII, M.XVI and Delicious seedling rootstocks under field conditions. A similar relationship was demonstrated in rooted layers of M.IX, M.VII and M.XVI.

When ^{32}P was applied to the scion leaves, the transport to the roots was directly related to the vigour of the plant with the exception of McIntosh/M.XVI. Since there were no significant differences between rootstocks in the ^{32}P content of the scion immediately above the bud union, this suggested that the bud unions formed by McIntosh on M.IX, M.VII, M.XVI and Delicious seedling did not differ in their capacity to transport ^{32}P during the times studied. Likewise, no significant accumulation of root-absorbed ^{32}P or ^{45}Ca was observed in the bud union segments (Tables I

PLATE I



FIG. 1.
Tanks used in growing the plants in which constant root temperatures were maintained.

and II). In root-absorption studies, the reduced quantity of ^{32}P and ^{45}Ca observed in the scions on the dwarfing stock (M.IX) may be attributed to reduced absorption or transport by the rootstock, or to a combination of the two processes, since they are interdependent, i.e. absorption must precede translocation.

It is conceivable that a limited supply of an essential nutrient or metabolite from the rootstock, or of a number of such, during early summer when the growth of the scion is at a maximum, may be partially responsible for the dwarfing response observed in the scion. The dwarfing effects of rings, interstems, and rootstock stems cannot be adequately explained by reduced absorption. They may, however, exert their influence by altering nutrient transport or the physiology of the plant, thus indirectly affecting nutrient uptake. Furthermore, the different transport rates observed in these studies may be a manifestation of some unknown factor or factors more directly responsible for the rootstock effect. In this connection, Rogers and Beakbane (1957) have noted the rôle of certain virus infections which have resulted in marked dwarfing responses without leaf symptoms.

It should be pointed out that the results obtained herein during the early growth may not be totally applicable to the behaviour of the plants at later growth stages or for time intervals other than the ones studied. In future work it would be interesting to determine the nature of the transport curves before 24 hours and after 96 or 144 hours following the isotope treatment.

SUMMARY.

A consideration of the transport of ^{32}P and ^{45}Ca in the apple (McIntosh on M.IX, M.VII, M.XVI and Delicious seedling) grown in solution cultures revealed that the transport rate of ^{32}P to the roots and scion and of ^{45}Ca to the scion closely paralleled the vigour observed in these plants under field conditions. Rooted layers of M.IX, M.VII and M.XVI transported increasing amounts of ^{32}P to the tops from solution cultures, in the order listed. No significant differences were noted in the ^{32}P content of the bud unions following foliar absorption of ^{32}P or root-absorption of ^{32}P and ^{45}Ca , during the first 96 hours following the isotope treatment.

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THE MINIMIZATION OF VARIABILITY IN EXPERIMENTS ON APPLES PLANTED ON THE SITE OF A PREVIOUS ORCHARD

I. THE EFFECT OF CULTURAL TREATMENTS ASSOCIATED WITH THREE YEARS' ARABLE CROPPING

By D. A. HOLLAND and D. W. P. GREENHAM
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MANY horticultural research stations face a serious shortage of experimental land, and several methods of economizing in such land have been suggested. Thus, intensive trials have been laid down using dwarf pyramid or cordon trees ; also, systems have been devised for using the same experimental material more than once (Pearce and Taylor, 1948 ; Hoblyn *et al.*, 1954), but sooner or later a plantation must be grubbed and it is important to know how soon and in what manner the land can be restored to an acceptable degree of uniformity.

Usually at East Malling the grubbing of an orchard is followed by a rotation of arable crops with the intention of restoring both fertility and uniformity to the soil. In the investigation to be described, two rotations, one of three years' duration and the other of seven, were tried with four cultural treatments ; but this paper will be concerned only with the plots that were arable for the shorter period.

The residual effects of the grubbed trees were studied both by analyses of soil samples and by growth measurements and chemical analyses made on plants subsequently grown on the land, especially young apple trees.

Since cultural practices such as applications of fertilizers can themselves affect soil variability (Hemingway, 1955), it was necessary to consider the effects of treatments not only on the clarity of the pattern of residual soil fertility left by the grubbed trees but also on random variation. In addition it was hoped that the form of the residual pattern would provide evidence throwing light on its cause and indicating possible methods of minimizing variability.

LAND AND MATERIAL.

The resources available for the investigation consisted of a four-acre plantation of Bramley's Seedling apples about 38 years old on largely unknown rootstocks and grown in clean cultivation on a fine sandy loam of the Malling Series (Bane and Gethin Jones, 1934 ; Furneaux, 1954). Such a soil is well aerated and free draining, unless the surface crumb structure is destroyed, when surface panning may result owing to the fineness of the sand particles.

The trees were planted in about 1913 at 12 feet square as part of a commercial plantation including some plums. After the orchard had been acquired by the Research Station in 1933, half the trees (selected on diagonals so as to include all

the plum trees) were removed by 1935, and then alternate rows were completely removed between 1937 and 1939 to leave the 24-foot-square plant which remained until the whole plantation was grubbed in January 1950. During the period from 1934 to 1949 the trees were used for experimental purposes but at no time were differential treatments employed such as might be expected to have had any effect on the soil or on the present problem.

The manner in which regular dressings of fertilizers were applied is of some importance since it may have played a part in the establishment of a regular pattern of soil variability. Little is known of the earlier years, but from about 1939 a drill some six feet wide was used. Owing to the form and spread of the trees, this drill was not able to approach more closely than about six feet from the bases of the trees. Thus the fertilizers were distributed along each alley in two strips each about six feet wide and frequently overlapping in the centre. In addition, these applications were invariably made in the north-south alleys except when very heavy dressings were involved, when the east-west alleys were also used. The distribution of fertilizers was, therefore, far from uniform but it followed a regular pattern. Furthermore, this, coupled with the fact that all spraying was also done from the north-south alleys, implies that these alleys supported most of the traffic in farm machinery through the plantation. It has been shown (Rodriguez-Ortiz and Crosby, 1956) that traffic in an orchard can change the physical condition of the soil and result in a reduction in the dry weight of roots per unit soil volume.

The investigation was started on the whole area of four acres as soon as the trees were grubbed in January 1950 but, after three years of arable cropping, apples were planted as an indicator crop on two acres for the short-term phase of the investigation here described, the other two acres continuing under arable crops for the long-term phase.

EXPERIMENTAL PROCEDURE.

In view of the probable existence of a pattern in the distribution of available nutrients, it was desirable that the effects of contrasting manurial treatments should be investigated. It was decided also to include cultivation treatments because of their probable modifying effect on any pattern of variation in physical properties of the soil, in addition to their expected influence on the distribution of nutrients. It was necessary, for practical reasons, to apply the cultivation and manuring treatments to comparatively large areas, not simply to localized areas surrounding each former tree site. Two levels of manuring, Rich and Poor, and two depths of cultivation, Deep and Shallow, were applied in conjunction with a three-year period of arable cropping. The details were as follows :

Arable cropping.

January 1950 ; old plantation grubbed.

March 1950 ; cultivation treatments applied.

May-October 1950 ; mangolds grown.

April 1951 ; ley sown, consisting of : Irish perennial ryegrass 6 lb. per acre,
Danish cocksfoot 6 lb. per acre, Broad Red clover 12 lb. per acre.

Summer 1951 ; ley gang-mown three times.

May 1952 ; hay crop taken.

October 1952 ; ley ploughed in.

Cultivation treatments.

- D, deep ploughing at eighteen inches after grubbing the old plantation.
 S, shallow ploughing at nine inches after grubbing the old plantation.

Manurial treatments.

R, a rich manurial programme as follows :

Before sowing mangolds ; 5 cwt. per acre muriate of potash, 3 cwt. per acre superphosphate, 1 cwt. per acre sulphate of ammonia.

Top dressing to mangolds ; 1 cwt. per acre sulphate of ammonia.

Before sowing ley ; 1 cwt. per acre muriate of potash, 3 cwt. per acre superphosphate, 2 cwt. per acre sulphate of ammonia.

Ploughed in with the ley ; 30 tons per acre farmyard manure.

P, a poor manurial programme as follows :

Top dressing to mangolds ; 1 cwt. per acre sulphate of ammonia.

Before sowing ley ; 1 cwt. per acre sulphate of ammonia.

These treatments were arranged in a split-plot design with the cultivation treatments on the main plots and the manurial treatments on the sub-plots, with four-fold replication of the cultivation $\times$ manuring treatment combinations. By making the plots large it was possible to simulate normal, full-scale, commercial conditions when applying the treatments. Thus, the main plots contained two rows of eight former tree sites and the sub-plots two rows of four. By regarding the Shallow/Poor treatment combination as representing no special treatment at all but a standard, the Shallow/Rich combination may be regarded as representing Rich manuring, the Deep/Poor as representing Deep ploughing and the Deep/Rich as the combination of the two.

About each former tree site a set of sampling positions was arranged, from which records could be made at any phase of the trial, in such a way that it would be possible to differentiate between the tree rows and the alleys in both the north-south and the east-west directions as well as different distances from the former tree sites. These positions, shown diagrammatically in Fig. 1, consisted of the site of the former tree itself (*T*), half-way between trees in the north-south direction (*Y*) and in the east-west direction (*X*), a quarter of the way between trees in the north-south direction, i.e. six feet to the north and six feet to the south of each tree (*Q*), and in the middle of the 24-foot square formed by four trees (*M*). Positions *X* and *Y* were those from which trees were grubbed between 1933 and 1935 and position *M* was that from which the trees were grubbed between 1937 and 1939 ; position *Q* on the other hand had never had a tree. At the time of grubbing, markers were buried at each corner of the plantation so that it was possible at any time to locate each of these positions accurately in the field.

In January 1953, at the end of the three years' crop rotation, the apple indicator crop was planted at a spacing of 6 feet in the rows and 12 feet between rows, rows running north to south, so that all sampling positions were occupied by indicator plants. In an attempt to eliminate the nursery as a factor contributing to the variability of the plant material, this indicator crop was planted as M.VII rootstocks which were cut back to 18 inches after planting and budded *in situ* with the variety Cox's Orange Pippin in July 1953. As an insurance against a poor "take" of buds

three rootstocks were planted and budded at each planting station, one at the true position, one at six inches to the north, and one at six inches to the south of it. Normal nursery procedure followed, whereby the rootstocks were cut back to about nine inches above the bud during the winter 1953/4 and finally cut back to the scion shoot in late summer 1954. The resulting groups of maiden trees were thinned to single trees in February 1955 by the rejection of all bud failures, damaged trees and those less than 50 cm. in height above the union, and the retention in each group of the tree which had made the most growth. A comparison of growth records made on all trees with those made only on those selected gave no reason for suspecting such a method of having introduced any bias into the experiment.

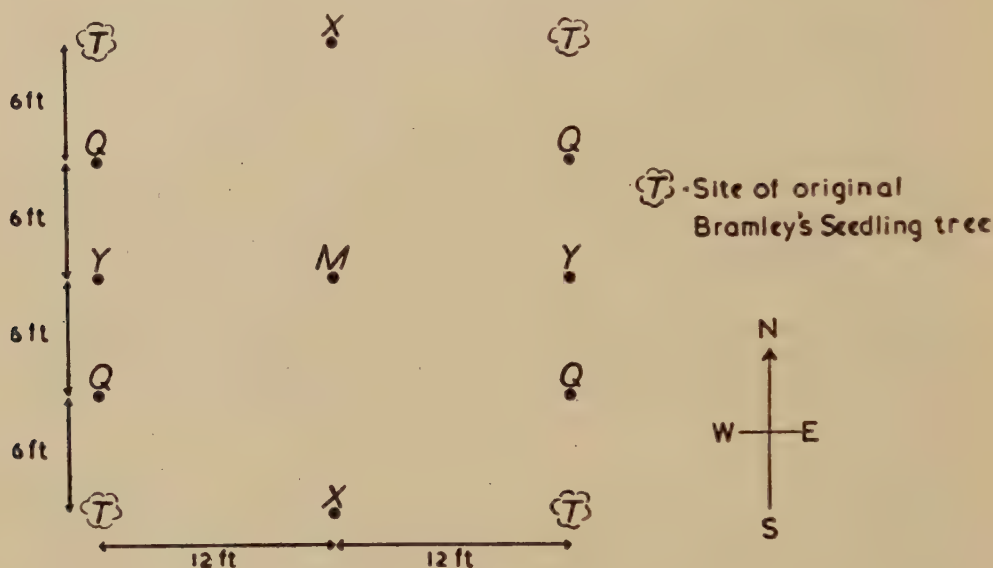


FIG. 1.
Arrangement of sampling positions.

The technique of forming experimental trees by budding rootstocks *in situ* was not, in this instance, entirely successful; the resulting growth was poor and many buds failed to grow out, producing only a rosette of leaves. Consequently, after thinning, there were a number of gaps which had to be replanted, the replants being, of course, omitted from the experimental records. Nevertheless, it was possible to designate four complete sets of sampling positions in each sub-plot for future recording. To avoid the introduction of a further factor which would complicate the interpretation of growth records, the trees were not pruned.

During the second year of growth of the scions, 1955, a few experimental trees were lost or damaged by wind and canker, and later in the year considerable damage was caused by a hare. While most of the damage occurred after growth had ceased, the growth records therefore not being greatly affected, a number of trees were rendered so abnormal as to be of little future value experimentally. Recording of

the indicator trees was therefore discontinued at this stage and all the trees were grubbed in March 1956.

The poor growth of the apples caused some doubt to be thrown on their sensitivity as an indicator crop. As a check they were immediately followed by a second indicator crop of mangolds, sown in April 1956 without the application of further treatments designed to overcome residual effects of the original plantation.

STATISTICAL APPROACH.

The intensity of the residual pattern left by the former trees and the effect of the treatments thereon could be assessed by considering the ease with which differences between sampling positions were detected, the form of the residual pattern being indicated by the nature of these differences for each of the four treatment combinations. Normally this would be achieved by considering the three-factor interaction, Ploughing $\times$ Manuring $\times$ Positions, in an analysis of variance for a double split-plot design with Sampling Positions forming the sub²-plots. The validity of such a practice is, in this instance, questionable in view of the possible effect, already referred to, of the treatments on random variability and the subsequent heterogeneity of errors. Consequently it becomes necessary to partition the data into four groups, corresponding to the four treatment combinations, and carry out four separate analyses of variance for the comparison of sampling positions on each treatment combination.*

Though satisfactory for a study of the form of a residual pattern, such an approach is inadequate for an assessment of the intensity of such a pattern, since the ease with which differences between sampling positions are detected depends on the magnitude of the random error as well as on the magnitude of observed differences between position means. Further, for such a method to be fully efficient, it is desirable first to formulate a hypothesis as to the form any residual pattern will take so that certain effects can be nominated in the analysis. The residual pattern, however, may be the result of systematic variation in (a) the availability of nutrients, and (b) the physical condition of the soil, the latter probably playing a large part in the initial establishment of the indicator trees. A pattern in the available nutrients may be the result of (i) distance of the sampling position from the site of a former tree, (ii) time elapsed since a tree last grew at a sampling position (note the earlier thinning of the original plantation) and (iii) uneven distribution of fertilizers in the past due to the manner of application already referred to. A pattern of the physical condition of the soil could be the result of (i) an opening up of the soil by the root systems of the former trees, (ii) disturbance of the soil when grubbing and (iii) soil compaction by the passage of farm machinery tending to work the plantation always by the same route. With so many factors, any of which could be dominant, it is not possible to formulate, with any reasonable degree of confidence, a hypothesis as to the form

* Actually the sampling positions were arranged systematically so that M , for example, was always farther from T than was Q and the error of an $M-T$ comparison could therefore be expected to be greater than that for a $Q-T$ comparison. There were, however, several sets of positions in each sub-plot, so that any comparison of sub-plot means for positions was not confined to adjacent positions; any Q position would be equally compared with a T position at the far end of the plot as with one adjacent. The resulting degree of heterogeneity was therefore likely to be too small to merit the considerable amount of computation necessary for taking it into account and analyses were carried out as if positions were randomly disposed.

of the residual pattern to be expected, and so to nominate effects in an analysis of variance. As a means of assessing the intensity of a residual pattern the ease with which differences between sampling positions can be detected cannot effectively be used.

A more direct approach is through the variances involved. From each of the four analyses it is possible to form estimates of σ_r^2 , the random component of variance, and of σ_p^2 , the component of variance attributable to the effect of any residual pattern. A comparison of the four values of σ^2 arising from the cultural treatment combinations will indicate the effect of cultural practices on random variation, while a similar comparison of the four values of σ_p^2 will indicate their effect on the residual pattern, or systematic variation, left by the original plantation.

The essential problem, however, is with the resulting error variance to be found in subsequent apple trials planted on this land. If such trials were designed so that trees were planted only at similar positions, relative to the former tree sites, or in such a way that some allowance for the residual pattern could be made in the statistical treatment of the results, then the error variance would be σ_r^2 , but that would be a special case. In the general case of a trial so designed that no account could be taken of any residual pattern effect, the error variance would be given by $(\sigma_r^2 + \sigma_p^2)$ —assuming, of course, that other factors, such as inherent variability of material, efficiency of blocking, etc., remained unchanged. Strictly, such an estimate of the error variance would be true only for a trial in which the trees were planted exactly as the indicator trees from which the estimate was made, i.e. in the same rows and at the same spacing. For each of the hypotheses that have been suggested as possible causes of a pattern of variation, the maximum range of conditions is represented in the sampling scheme; σ_p^2 would therefore be maximized, and similarly the estimate of error variance, $(\sigma_r^2 + \sigma_p^2)$.

The ultimate question of the sensitivity of subsequent trials goes further than a consideration of the error variance to be expected and asks what percentage differences will these trials be able to detect. This will be dependent on the mean as well as on the variance and can therefore be conveniently expressed as the Coefficient of Variation (V_e) since the percentage difference that a subsequent trial would be capable of detecting significantly would be $V_e t \sqrt{\frac{2}{n}}$; where t = the appropriate value of "Student's" t , and n = the number of replicates.

The essential comparisons in this investigation are, therefore, between the four values of V_e , where $V_e = \frac{100}{m} \sqrt{\sigma_r^2 + \sigma_p^2}$ and m = the mean arising from each of the four treatment combinations. Similar values for V_r and V_p can be constructed, from σ_r^2 and σ_p^2 respectively, for the separate studies of the effects of treatments on random variability and residual pattern.

RECORDS AND RESULTS.

SOIL.

In December 1949, immediately before the original trees were grubbed, soil samples were taken from the depths 0-9 inches and 9-18 inches for the determination of pH and of nitrate nitrogen (in categories) and "available" phosphate and potash

PLATE I



FIG. 2.

Mangolds : 1950 (above) and 1956 (below), photographed from a height of 68 ft. Positions of former trees at the ends of the rows shown by white markers.

(as parts per million of phosphorus and potassium) in Morgan soil extracts (Morgan, 1937). Initially these samples were taken from the positions *T* (as near the trunk as possible) and *M* and a position (*H*) half-way between the two with a view to the detection of any association with distance from tree. The possible value of *X* and *Y* as sampling positions for the detection of differences between rows and alleys became apparent later, but by this time the trial had started and the cultivation treatments had been applied. A small area of the original plantation did remain, however, and a second set of soil samples was taken in March 1950 at 0.9 inches depth from *X* and *Y* over this area. Unfortunately a dressing of muriate of potash which had been applied a few days prior to sampling vitiated any useful comparison between *X* and *Y* as far as potash was concerned.

There was no evidence in the data to suggest that the observed relationships between *T*, *H* and *M* were dependent on the depth of sampling, so the results were averaged over the two depths and are given in Table I. Compared with *H* and *M*,

TABLE I.
Soil analysis, 1949-50.

	Sampling position* (depth 0-18 in.)			Significant difference ($P=0.05$)	Sampling position (depth 0-9 in.)		Significant difference ($P=0.05$)
	<i>T</i>	<i>H</i>	<i>M</i>		<i>X</i>	<i>Y</i>	
pH	7.27	6.99	6.87	0.12	7.32	7.49	0.15
Nitrate nitrogen (cate- gories)	2.5	5.5	6.4	1.7	2.0	2.4	not significant
Phosphorus (p.p.m. in extract)	2.9	2.1	2.6	0.3	4.9	5.5	
Potassium (p.p.m. in extract)	24.4	27.3	26.3	2.0	—	—	—

* See Fig. 1 and text.

the soil at the *T* position was high in pH and "available" phosphate, but low in nitrate nitrogen and "available" potash. Also in the same table are the results obtained from the samples of *X* and *Y* at 0.9 inches, showing pH to be somewhat higher at *Y* than at *X*. In a series of soil samples taken in 1949 from the other half of the area, to be used for the long-term phase of the investigation, a direct comparison of *X* with *T*, *H* and *M* showed *X* to be similar to *T*, and different from *H* and *M*, in pH, nitrate nitrogen and "available" phosphate; on the other hand, *X* was higher than *T* in "available" potash.

Soil samples from the two depths 0-9 inches and 9-18 inches were again taken in May 1954 and submitted to similar analyses. Positions *T*, *Q*, *Y*, *X* and *M* were sampled but no differences between these positions could be detected. The data did, however, confirm that cultural treatments can increase the error of such determinations. The random variation was significantly ($P<0.001$) increased by the Deep/Rich treatment combination in every instance.

In December 1950, following the mangold crop and before the ley was sown, a limited investigation was made of the physical condition of the soil. Determinations were made of the volume weight or bulk density of samples taken at the *T* and

X positions from both Deep and Shallow ploughed plots (Table II). On the Shallow ploughed plots, the soil was found to be more compact at the *X* position than at *T*

TABLE II.

Volume weight of soil, December 1950 (gm. dry soil per c.c. in 0-24 in. depth).

Treatment	Sampling position	
	<i>X</i>	<i>T</i>
Shallow	1.52	1.38
Deep	1.42	1.41

(significant at $P=0.05$), but the difference was overcome by Deep ploughing which opened the soil at *X* (the Treatments $\times$ Positions interaction was nearly significant at $P=0.05$).

MANGOLDS.

In September 1950, just prior to harvesting, small areas of mangolds corresponding to the former tree sites were observed to have distinctly pale green or yellowish foliage. This pattern is shown in a photograph (Fig. 2) taken from the top of a mobile fire escape at a height of 68 feet, with the positions of the former trees at the ends of the north-south rows indicated by white markers. The pattern was also well shown by an aerial photograph taken from 600 feet.

When the mangolds were harvested, records were made of the number and weight of roots and weight of tops at each sampling position. The sampling unit for this purpose was a six-foot length (three feet either side of the exact position) of two

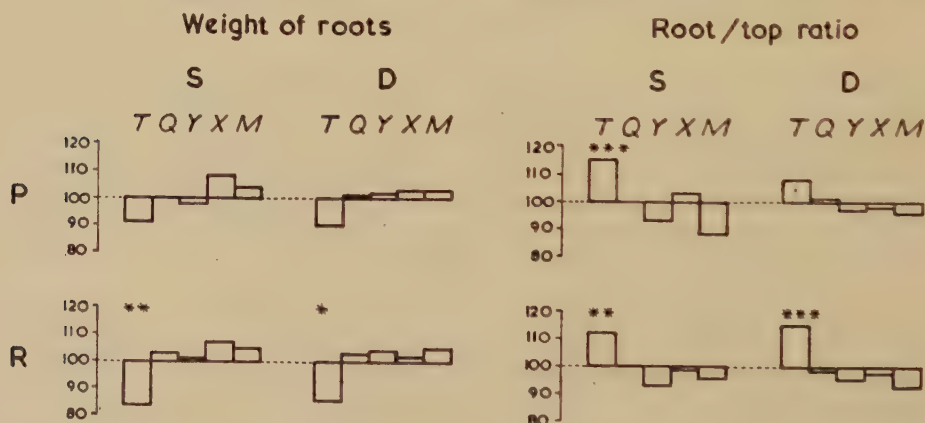


FIG. 3.

Weight of mangold roots, and root/top ratio, as percentages of treatment means (see also Table III).

* = positions differ significantly at $P=0.05$
 ** = " " " " " " $P=0.01$
 *** = " " " " " " $P=0.001$

TABLE III.
Weight of mangold roots, and root/top ratio.

	Weight of roots (lb. per double row of 6 ft.)		Root/top ratio	
	S	D	S	D
P	36	39	3.6	3.7
R	42	44	3.4	3.5

S, shallow ploughing ; D, deep ploughing.
P, poor manuring ; R, rich manuring.

adjacent north-south rows. No differences in the number of roots at the different sampling positions could be detected, so any differences in weight of roots must have been due to differences in size. In Fig. 3 the weight of roots at each sampling position and the corresponding root/top ratio are presented as percentages of the mean values (Table III) for all five sampling positions for each combination of cultivation and manuring treatments. In this and in subsequent figures, the sampling positions are arranged in the order of increasing distance from the tree position (*T*), except that *Y* and *X* are equidistant from *T*.

TABLE IV.
Chemical composition of mangold leaves, October 1950, from each sampling position as percentages of the treatment means.

Treatment	Mean (per cent. dry weight)	Position					Sig. diff. ($P=0.05$)
		<i>T</i>	<i>Q</i>	<i>Y</i>	<i>X</i>	<i>M</i>	
Shallow/Poor ..	N 4.20	86	107	100	94	113	13 not significant
	P 0.34	100	106	97	91	106	
	K 3.36	110	102	99	102	87	" 20 "
	Ca 1.32	115	113	84	97	91	
	Mg 0.46	85	131	103	94	87	
Shallow/Rich ..	N 4.20	77	100	104	111	108	13 not significant
	P 0.36	94	94	100	108	103	
	K 3.08	98	112	114	93	83	" "
	Ca 1.30	122	102	100	78	98	
	Mg 0.46	97	97	107	97	103	
Deep/Poor ..	N 4.26	86	95	109	104	106	14 not significant
	P 0.34	91	97	102	99	111	
	K 2.92	130	98	83	93	95	26 not significant
	Ca 1.18	124	92	103	87	93	
	Mg 0.49	100	98	111	92	78	
Deep/Rich ..	N 4.34	86	100	106	101	107	not significant
	P 0.37	98	93	101	98	109	
	K 3.01	121	98	91	93	97	" 20 "
	Ca 0.43	116	98	99	105	81	
	Mg 1.27	94	108	106	94	97	

The mangolds which followed the apple indicator trees were photographed in October 1956 (Fig. 2) from the same viewpoint as those of 1950. This time no such pattern as that seen on the previous occasion was discernible. Records were also made of the number and weight of roots and the weight of tops as before but, as with the photograph, no differences could be detected.

On both occasions leaf samples were taken at the time of harvesting and chemically analysed for nitrogen, phosphorus, potassium, calcium and magnesium (Table IV). The outstanding feature of these results is the consistently low level of nitrogen at the *T* position. No differences were found in 1956.

LEY.

From a survey made in June 1952, no differences between positions (*T*, *Y* and *Q* were sampled) could be detected in the degree of cover or in the amounts of clover or cocksfoot present in the ley. Leaf samples of cocksfoot taken at this time were chemically analysed, as had been the mangold leaves, and the results are presented in Table V in the same way.

TABLE V.

Chemical composition of cocksfoot leaves, June 1952, from different sampling positions as percentages of the treatment means.

Treatment	Mean (per cent. dry weight)	Position			Sig. diff. ($P=0.05$)
		<i>T</i>	<i>Q</i>	<i>Y</i>	
Shallow/Poor	N 2.86	99	100	101	not significant
	P 0.39	107	98	95	6
	K 3.95	102	98	100	not significant
	Ca 0.59	106	97	97	" "
	Mg 0.25	108	96	96	10
Shallow/Rich	N 2.75	100	99	100	not significant
	P 0.37	104	99	97	5
	K 3.87	100	99	101	not significant
	Ca 0.64	101	94	105	" "
	Mg 0.25	109	93	97	9
Deep/Poor	N 2.90	97	101	102	not significant
	P 0.41	104	101	95	4
	K 4.01	102	101	97	not significant
	Ca 0.64	100	94	106	9
	Mg 0.27	105	94	101	not significant
Deep/Rich	N 2.74	102	97	101	not significant
	P 0.39	104	97	99	" "
	K 3.99	100	98	102	" "
	Ca 0.63	104	90	106	10
	Mg 0.26	101	94	105	not significant

APPLE TREES.

Vegetative growth.

Records were made of the trunk girth at planting and at the end of each growing season, the measurements of the rootstocks (at planting and in winter 1953/4) being made at three inches above soil level and those of the scions (winters 1954/5 and

1955/6) at six inches above the union. Similarly the total length of new shoots was measured for each rootstock in the winter 1953/4 and for each scion in the winters 1954/5 (length of stem and feathers) and 1955/6. The weight of each scion was also recorded when the trees were grubbed, the scion then being two years old.

From these records values of V_r , V_p and V_e have been calculated, in the way already described, for final tree size (as measured by girth, total length of shoots grown from the scion bud, and weight of scion) and for increments in girth and length of new shoots made in the growing seasons 1953, 1954 and 1955. All these values are set out in Table VI. The rootstock girth increments made in 1953 were adjusted according to the girth at planting by covariance methods.

TABLE VII.
Annual growth increments of apple indicator plants.

		Trunk girth (cm.)		Extension growth (cm.)	
		S	D	S	D
1953 (rootstock) ; increment in trunk girth and length of new shoots	P	1.14	0.97	75	70
	R	1.11	1.21	78	88
1954 (scion) ; girth of main shoot grown from the bud and length of all scion shoots	P	2.51	2.49	84	78
	R	2.52	2.65	80	84
1955 (scion) ; increment in trunk girth and length of new shoots	P	1.59	1.66	198	189
	R	1.61	1.85	192	260

S, shallow ploughing ; D, deep ploughing.
P, poor manuring ; R, rich manuring.

The nature of the differences constituting any residual pattern is shown in Figs. 4 and 5 where sampling position means are expressed as percentages of the appropriate treatment mean (Tables VII and VIII respectively). As with the mangold data (Fig. 3), the occurrence of significant differences between positions has been noted on these figures.

TABLE VIII.
Final size of apple scions.

		S	D
Trunk girth (cm.)	P	4.11	4.13
	R	4.13	4.50
Total shoot length (cm.) ..	P	310	292
	R	300	374
Fresh weight (hg.)	P	1.74	1.64
	R	1.70	2.12

S, shallow ploughing ; D, deep ploughing.
P, poor manuring ; R, rich manuring.

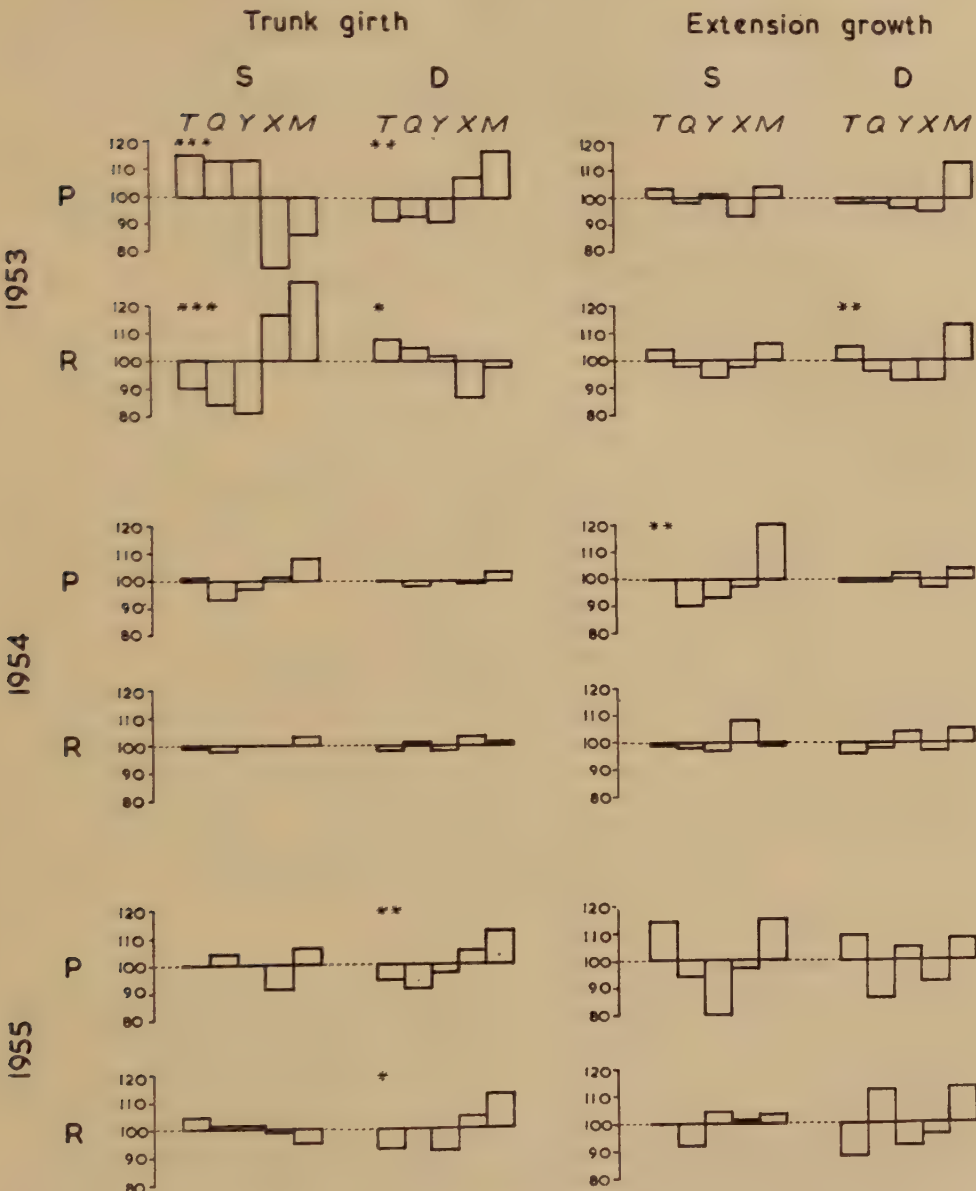


FIG. 4.

Annual growth increments of apple indicator plants as percentages of treatment means (see also Table VII).

* = positions differ significantly at $P=0.05$
 ** = " " " " $P=0.01$
 *** = " " " " $P=0.001$

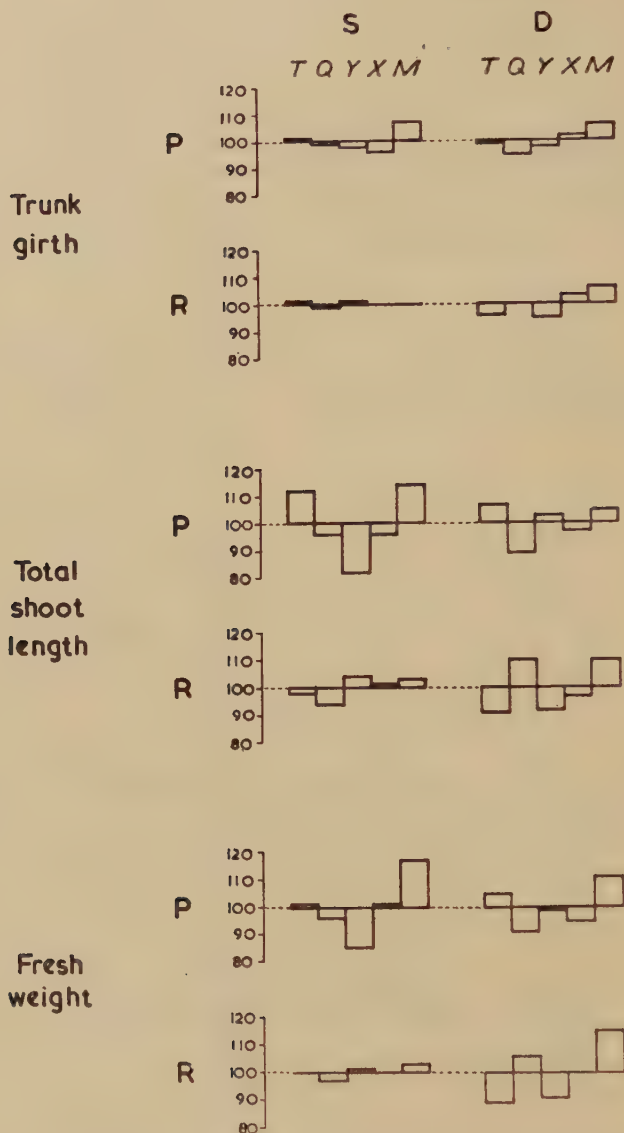


FIG. 5.

Final size of apple scions as percentages of treatment means (see also Table VIII).
In no case do positions differ significantly at $P=0.05$

Leaf analyses.

In August 1954 (the first year of growth of the scion) and again in August 1955, samples of the youngest fully expanded leaves on new shoots were taken and chemically analysed for nitrogen, phosphorus, potassium, calcium and magnesium. On neither occasion was there any pattern of differences between sampling positions in

chemical composition of the leaves, except for potassium (Table IX). In both years there were differences in potassium content with the Shallow/Poor treatment combination (significant at $P=0.01$ in 1954 and at $P=0.05$ in 1955) and the data suggest a similar, though non-significant, pattern with Deep/Poor; these differences were not apparent where the Rich manuring treatment had been applied.

TABLE IX.

Potassium content of apple leaves from each sampling position as percentage of the treatment means.

Year	Treatment	Mean (per cent. dry weight)	Position					Sig. diff. ($P=0.05$)
			T	Q	Y	X	M	
1954	Shallow/Poor ..	1.73	89	96	98	103	114	12
	Shallow/Rich ..	2.01	96	103	102	100	98	not significant
	Deep/Poor ..	1.71	94	93	101	107	105	" "
	Deep/Rich ..	1.98	98	98	98	99	106	" "
1955	Shallow/Poor ..	1.59	92	94	109	102	103	9
	Shallow/Rich ..	2.06	99	98	100	99	104	not significant
	Deep/Poor ..	1.55	91	96	97	107	110	" "
	Deep/Rich ..	1.93	97	101	102	101	99	" "

Other records.

In 1953 and 1954 a considerable amount of interveinal leaf scorch was recorded, but statistical analysis showed no association between the degree of scorching and sampling position.

Finally, when the trees were grubbed, root samples were taken and examined in the laboratory for the presence of nematodes. None was found, however, which suggests that nematode infestation, if present, was very slight and therefore unlikely to have been a factor contributing to any residual pattern.

DISCUSSION.

From the values of V_r , V_p and V_e given in Table VI it is apparent that, in general, and particularly so where final tree size was concerned, the variation attributable to a residual pattern was small relative to random variation and, as far as annual growth records were concerned, was not consistently affected by any one treatment. The notable exception to this was with girth increment of the rootstocks in the first year after planting, viz. 1953. In this instance the residual pattern was much more marked and was considerably reduced by the deeper ploughing and even further reduced by the additional employment of a rich manurial programme during the period of arable cropping. For final tree size the variation due to a residual pattern was so small in comparison with the random variation as to be negligible. Random variation in annual growth increments was similarly not affected consistently by any one treatment; Deep ploughing, particularly in conjunction with Rich manuring, was most effective in bringing about a reduction in some cases, Rich manuring alone in others, while all treatments increased the random variation in the length of shoot

made from the scion bud in 1954. For final tree size, however, random variation was consistently reduced by Deep ploughing with some further, but slight, reduction arising from Rich manuring in addition.

These results suggest that, since treatments differ from year to year in their ability to minimize positional variation in annual growth increments and since the accumulated effect over a period of two years is for positional variation in tree size to be negligible, the relatively low variation attributable to a residual pattern may be the result of different limiting factors from year to year which in turn give rise to patterns of differing forms. It therefore becomes pertinent to consider the qualitative nature of the residual pattern or patterns and hence the possible causes of inter-positional differences.

As has already been pointed out, the most pronounced patterns detected were those shown by the girth increments of the rootstocks in the year of planting (Fig. 4, 1953); for every treatment combination this pattern was basically a distinction between rows (*T*, *Q*, *Y*) and alleys (*X*, *M*) in the north-south direction, but the effect with two of the treatment combinations (Shallow/Poor and Deep/Rich) was opposite to that with the other two. A clear pattern in which rows are contrasted with alleys was also shown by the girth increments of the scions (1955) on the Deep ploughed plots. The only other measurements on the indicator plants to show significant residual patterns were those of new shoot length of the rootstocks (Fig. 4, 1953) on the Deep/Rich plots and of the scions (Fig. 4, 1954) on the Shallow/Poor plots; in both cases the greatest growth was shown at the *M* position, while the rootstocks on the Deep/Rich plots also made more extension growth at the *T* position than at *Q*, *Y* or *X*. Thus measurements of lengths of shoot did not reveal patterns which could be related to residual differences between rows and alleys.

These data (Figs. 4 and 5) show no consistent evidence of a pattern related to distance from tree position, except in a tendency for the greatest growth to occur at the *M* position. There was certainly no tendency for growth to be least at the *T* position, as had been seen in the mangold crop (Fig. 3). Differences had been found between *T* and other positions in soil analyses (Table I) and in the chemical composition of mangold (Table IV) and cocksfoot (Table V) leaves, but these differences evidently were not related to the growth of the indicator trees. The poor growth of the mangolds at the *T* position in 1950 was probably due to severe nitrogen deficiency (cf. Table I) arising from locally poor nitrification conditions, but the absence of this type of pattern from the succeeding ley and from the 1956 mangold crop, as well as from the indicator trees, suggests that this source of variation was quickly eliminated. The relatively high "available" phosphate at the *T* position (Table I) was reflected in the composition of the cocksfoot leaves (Table V) but not in that of the indicator trees. The leaves of the indicator trees showed positional differences in chemical composition only in the case of potassium (Table IX), the concentration tending to be low at the *T* position (cf. Table I) but, as already seen, this was not reflected in the growth of the young trees.

Thus, while the grubbing of the old plantation undoubtedly left a residual pattern characterized by differences between the tree position itself and all other positions, as is shown in the data for the soil and the arable crops, such a pattern was evidently quickly confused to such an extent as to have no observable effect on the growth of the indicator trees. On the other hand, the indicator trees gave clear evidence of the persistence of patterns showing contrasts between rows and alleys in

the north-south direction. Although the detailed effects observed, particularly on the girth increments of the rootstocks in 1953, cannot easily be explained, it is probable that such patterns arose either from the physical condition of the soil (with its effect on soil moisture relationships and the establishment of young trees), as suggested by the compaction of the soil in the north-south alleys (Table II), or from the previous practice of distributing fertilizers along these alleys (supported, at least in respect of applications of sulphate of ammonia, by the lower pH at X than at Y, cf. Table I) or from a combination of both factors. Thus, it would seem that the residual patterns shown by the indicator trees were broadly related not so much to the positions of the old trees as to the cultural practices carried out in the old orchard.

Although the persistence of these patterns is of some interest, it must be emphasized, however, that their contribution to the total variability (except in the first-year girth increments of the rootstocks) was negligible. The random variation was far more important. It could have been concluded from a consideration of residual patterns only (Figs. 4 and 5) that the Shallow/Rich treatment was the most effective in reducing variation, for the trees of that treatment showed no important differences in position (again excepting the girth increments of the rootstocks). However, since this treatment did not result in consistent reductions in random variation (Table VI), and since the variation due to residual pattern was small in any case, the Shallow/Rich treatment was by no means the most effective in reducing total variation.

Useful guidance to the experimenter is provided by the effects of treatments on total variation, and not merely by the intensity of residual patterns. From the data obtained in this phase of the present investigation, it may be concluded that, combined with a three-year sequence of arable crops, deep ploughing following grubbing was more effective than shallow ploughing in reducing the variability in size at two years old of a subsequent plantation of apples, and that this was still true when rich manuring was employed during the period of arable cropping, a practice which may be considered necessary for the restoration of soil fertility.

SUMMARY.

1. Following the grubbing of a mature orchard of Bramley's Seedling apples an investigation was made into the effectiveness of deep (18 in.) or shallow (9 in.) ploughing immediately after grubbing, and of a rich or poor manurial programme during the ensuing three-year period of arable cropping, on the restoration of uniformity of the soil and its suitability for further experimentation on apples.

The effects of these treatments were assessed through a study of the variation of the arable crops and particularly of an apple indicator crop planted at the end of the three-year period of arable cropping.

2. Although a residual pattern directly related to the old tree positions was shown in the mangold crop, this type of pattern was not apparent in the apple indicator trees. Such patterns as were shown by the apples were mostly related to the paths of movement of tractors and implements and the distribution of fertilizers in the old orchard and it is therefore concluded that the residual patterns were largely the result of past cultural treatments rather than of the siting of the trees themselves.

3. The contribution of the residual patterns to the total variability of the apple indicator crop was negligible (after the first year) compared with the random component of variability. The effectiveness of cultural treatments in reducing the variability of subsequent trials is thus largely dependent, not on the persistence of a residual pattern, but on the reduction in random variability.

4. Deep ploughing was more effective than shallow ploughing in reducing the variability in size of the indicator trees, this effect being independent of the manurial programme employed.

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The authors would like to stress the collaborative nature of this investigation and accord their thanks to many colleagues at East Malling, especially to Mr. T. N. Hoblyn, Dr. W. S. Rogers and Dr. S. C. Pearce, for their constant help and advice. Particular thanks are also due to Mr. A. C. Mason (leaf analyses), Mr. J. E. Goode (soil factors), soil chemists at the Wye sub-centre, S.E. Region, N.A.A.S. (soil analyses) and Dr. R. S. Pitcher (nematodes) for their specialized advice and assistance; to Mr. E. Y. Jones who, with the co-operation of the Kent County Fire Department, took the photographs; to No. 657 Air O.P. Squadron, R.A.F., Middle Wallop, who took the aerial photograph referred to in the text; to Miss E. M. Glenn and her assistants for help with the field recording; to Messrs. G. F. W. Buckland and G. E. Davies for their routine supervision of the trial in its early stages, and to Mr. F. H. Villiers and the farm staff for their patient co-operation.

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TECHNIQUE AND PRELIMINARY OBSERVATIONS ON GROWTH OF THE ROOTS OF GLASSHOUSE TOMATOES IN RELATION TO THAT OF THE TOPS

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SYNOPSIS.

The use of glass-sided boxes and trenches for observing the growth of the roots of glasshouse tomatoes has been investigated. Marked seasonal trends have been found with two varieties in two years. There was a rise to a peak followed by a rapid fall in total root length, due to death and disappearance of the roots, with a subsequent recovery. This trend occurred in all horizons of soil.

Growth of the stem and leaves was relatively steady from planting-out (March) until mid-May, when there was a slight decrease with subsequent recovery until the main stem and laterals were "stopped" in July.

The number of flowers per truss was high in the bottom five or six trusses, in which fruit set was high, fell in the median trusses which had low set, and rose in the uppermost trusses accompanied by increased set. The resulting production of fruit weight was high in the bottom trusses and low in the top.

The peak of root length development coincided with the swelling of the fruit in the bottom trusses; a trough occurred when the number of flowers per truss and the number set were low, and root length recovered when the first trusses were picked.

THE commercial glasshouse culture of tomatoes has evolved practices which, with local and individual variations, have become relatively standardized. Investigations on certain aspects of these practices have been made. Thus, earlier publications from the Research Institute of Plant Physiology on work carried out at the Cheshunt Experimental Station (Bolas and Melville, 1933; Selman, 1934; Melville, 1937; Bolas *et al.*, 1938; Goodall, 1945) dealt with the interaction of light and temperature on assimilation and translocation at the eight-leaf stage, that is, at about the stage of development at which tomatoes are planted out in commercial practice and before the change from purely vegetative to reproductive activity is evident externally.

A start has now been made on investigations of the growth of tomato plants during the reproductive phase in a glasshouse border, with the aim of rationalizing normal cultural practices by ascertaining their effects on the trends of growth throughout the season. In particular, data have been obtained on the growth of the root, a relatively neglected plant organ.

The present contribution embodies the results obtained in the first two years, during which all cultural operations were carried out by the nursery staff according to the normal commercial practice for the varieties. This involved removal of

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the majority of the lateral shoots and leaving one or two per plant according to its vigour. Owing to the limited height of the glasshouse, it was necessary to remove the growing point of the plants (to "stop") in early July. After this date, therefore, the records cease to be those of the growth of an indeterminate plant.

METHODS.

Since glass-lined trenches and glass-sided boxes were to be used for observing root growth, it was necessary to determine the maximum depth to which tomato roots extend in a glasshouse border under commercial practice in the soil at Cheshunt. The root systems of a row of four plants were excavated towards the end of the growing season (mid-August), using the "soil-block" technique. Since the roots from adjacent rows may be expected to intermingle at a fairly early stage, it was decided to take the mid-way line between rows as an arbitrary boundary.

As to the results obtained from this block survey, it is sufficient for the present to state that no marked differentiation into contrasting types of root, such as occurs in cereals, was found, nor was there any evidence of suberization. The root diameter decreased from a maximum of about 4 mm. at the hypocotyl to less than 1 mm. There was restricted development of skeletal roots, some three or four branches extending only for a short distance from the hypocotyl, from which a large number of secondary adventitious roots originated. The roots were freely branching and branches of up to the seventh order were observed in another plant washed out from a pot; the roots penetrated to slightly below 80 cm. (2 ft. 8 in.) but the lowest layer examined, namely 70–80 cm., contained less than 1 per cent. of the total root length.

Preparation of glass-lined trenches and glass-sided boxes.

On the basis of these data a trench 2 ft. 8 in. deep and 4 ft. long was dug, this being the maximum possible length between the two rows of hot water pipe running the length of the border. The walls of the trench consisted of welded angle iron frames carrying $\frac{1}{4}$ in. wired "Georgian plate glass". In the first year (1951) one side of the trench was vertical, the other sloping, with a width of 1 ft. at the bottom and 2 ft. at the top. In the second year both sides were made vertical. The top and bottom angle irons of the frames had extensions so that trench struts could be used to keep them apart against the pressure of the soil. In excavating the trench, situated mid-way along a border and running east and west, the soil as removed was kept separate in its respective horizons. There was a clearly marked change at 30–35 cm. (12–14 in.) from medium light loam to yellow Lea Valley gravel and stones. It was found difficult to maintain a good contact between the large glass faces and the undisturbed, irregular gravel faces at the bottom of the trench, so that, in the first year, below about 40 cm. (1 ft. 4 in.) there were considerable gaps between the glass and the soil. The upper, cultivated layer of soil was replaced and firmly rammed into position so as to maintain good contact with the glass, and in the second year sieved soil was used to fill any gaps between the gravel and the glass. The border soil had been steam-sterilized after removal of the previous year's crop of tomatoes, and winter-flooded each year, thus following normal commercial practice. The ends of the trench were closed with wood shuttering, behind which soil was replaced. The dimensions of the trench were about minimal for comfortable observation of the glass faces.

A glass-sided box was also constructed from similar glass sheets in frames of the same angle iron. In the first year it had one vertical glass side, 4 ft. by 2 ft. 8 in., and one sloping side so arranged that the bottom edge of the sloping face was vertically below the centre of the top of the box. In the second year both sides were made sloping, at the same angle, with a width of 2 ft. at the top and tapering to 1 ft. below, and the two frames holding the glass were bolted together with ties of the angle iron. The 2 ft. width of the top of the box represents the space which would be available to the roots of a single row of plants if there were no overlap of roots between adjacent rows.

The box was filled from the excavated soil replaced in the correct order of horizons and firmly rammed. Arrangements had been made for hoisting the box clear of the trench for purpose of observation, but the sloping face cracked soon after filling and it was judged prudent, for the first year, to abandon the plan of lowering the box into the trench, instead of which it was placed on the adjacent border of the house. This introduced several differences in the environment of the plants in the box from those in the border, especially as regards their roots. During the second year the box, except during observations on the roots, was kept in the trench until mid-April, at which time the tops of the plants began to foul the hoisting and traversing gear. The box was then placed permanently on the adjacent border and asbestos cement sheets were used to exclude light from the glass sides and to reduce the daily temperature range of the soil. Each year the trench was covered with a wooden lid.

Observations of air temperature at 4 ft. above ground level in a screen and of soil temperature at different depths were made; also of the duration of bright sunshine by a Campbell-Stokes recorder outside the glasshouse.

Observations on the plants.

Tomato plants, sown in boxes and transferred to 3½ in. clay pots, were planted out at the eight-leaf stage, when about 6 in. high. In the first year the variety was Potentate, planted out on 19th March, and in the second year Ailsa Craig, planted out on 29th February. Three plants were placed centrally in the box, i.e. 1 ft. from either glass face. In the trench four plants, at the normal commercial spacing, were set alongside each face, six inches from the glass.

Tops. Weekly measurements were made of total stem length (to the nearest centimetre) from the soil surface to the apex of the plant, and similar ones of laterals from their point of origin on the main stem. The number of leaves on the main stem and on laterals was determined, an operation which was facilitated by marking every tenth leaf. The trusses (flower clusters) were counted and classified into five successive stages of development. Ripe fruits were weighed on picking to the nearest gram and their colour noted. Additional observations made on the flower trusses were flower dropping and "dry set" (the condition when the flowers did not drop but the ovary did not enlarge beyond about ⅓ in. diameter).

Roots. Using the inset wires (½ in. apart) as a reference grid, observations were made on the roots as seen through the sheets of glass, so that the position, depth and alignment of each root was recorded, a procedure similar to that adopted by Rogers (1934). The length of each continuously visible root was measured with a transparent rule to the nearest millimetre. Branches of roots were similarly recorded and the grand total of root length on each occasion obtained. Separate records were

made of roots apparently dead. Some discrepancies, due apparently to differences in the two alternate observers' estimates of root viability, are evident in the records obtained in 1951. In 1952 successive measurements on each glass face were made by one observer. The number of individual roots or root tips cannot be ascertained from the number of measurements recorded on each occasion, since individual roots may be interrupted in their contact with the glass, or the tip may not be visible. To determine the changes occurring at different depths in the soil, subdivision of the roots into successive 10 cm. horizons, by use of the numbered squares, was carried out.

In the first year the main object was to explore the possibilities of the glass panel method as a means of following the development of a section of the root system throughout the growing season. Hence two different distances from the plant and three different slopes of the glass were used. In the second year the aim was to seek information on the reliability and reproduceability of the method by comparing data from two panels at the same slope on opposite sides of a row of plants (in the box) and from two vertical panels adjacent to two different rows of plants (in the border). These aspects will be dealt with first, after which the growth trends observed will be discussed.

OBSERVATIONS ON THE RELIABILITY OF THE GLASS PANEL METHOD.

Comparison of length of roots visible in glass panel and present in volume of soil.

By early June in the first year, the plants in the box had grown to the scaffolding and would soon have been touching the glass roof. The growth of algae on the inner face of the glass was beginning to make observation of the roots difficult and, as the amount of time spent in collecting the data from the box and trench became considerable, weekly records could no longer be maintained. It was therefore decided to conclude the observations, harvest the plants in the box and make a "soil block" survey of the roots to allow of a comparison of the total amount of root present in the body of the soil with that observed at the glass faces. The data will not be detailed here. Measurements were obtained to a depth of 40 cm. along the vertical face of the box; in the time available, it was not possible to carry them beyond 20 cm. depth on the sloping face.

TABLE I.

Correlation between length of roots observed on glass panels and that of roots within neighbouring mass of soil.

Horizon	Length of root (cm.)			
	Vertical face		Sloping face	
	Observed at glass (x)	Found in soil (y)	Observed at glass (x)	Found in soil (y)
0-5 cm.	0	1,807	0	1,885
5-10 cm.	8.9	2,790	9.2	2,761
10-20 cm.	32.6	9,682	43.8	7,832
20-30 cm.	39.0	7,691	—	—
30-40 cm.	33.2	7,126	—	—
	$y = 1,667 + 182.56x$		$y = 1,707 + 138.74x$	

Table I gives the total length of roots, less than 1 mm. diameter, observed in the different horizons at the two glass faces and the corresponding total found in the layer of soil 10 cm. inwards from the glass face. The length of roots found in the blocks of soil against the sloping face has been adjusted for the reduction in volume.

While the number of observations is regrettably low, both sets of data obviously conform to a direct proportionality. Correlation for the data from the vertical face was $+0.93$ with a probability of 2 per cent. ; the three values for the sloping face

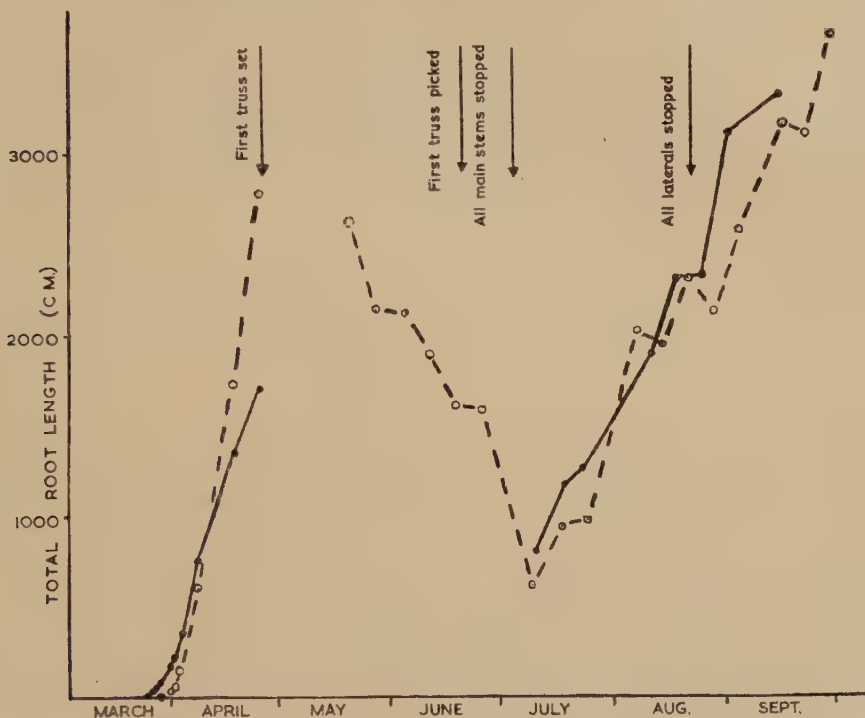


FIG. 1.

Total length (cm.) of root visible in north (continuous line) and south (broken line with circles) glass walls of box. Lighter segment of broken line (20th-27th May) indicates period when data was obtained from sample panels. Ailsa Craig, 1952. Arrows indicate stages of development of trusses, leaves and laterals.

gave an even higher correlation. It may therefore be concluded that the length of visible roots closely reflects the total root length in the various layers.

A similar relationship was found by Davis (1940). He grew maize in a glass-sided box and determined the root content of adjacent blocks of soil. He found a correlation of $+0.81$ with the root length observed through the glass.

Comparison of lengths of root visible in opposite glass panels of glass-sided box and in opposite faces of trench.

The second year's observations permit a direct comparison between the length of roots visible in the two glass panels of the same dimensions, first with the box which

had a single central row of plants and sloping glass sides distant 1 ft. at the top and 6 in. at the bottom from the central plane; and secondly with plants arranged in two rows on opposite sides of a trench, each row 6 in. from the vertical glass sides.

For the first part of the season the box was raised out of the trench only when it was required to make observations on the roots. Consequently the plants were

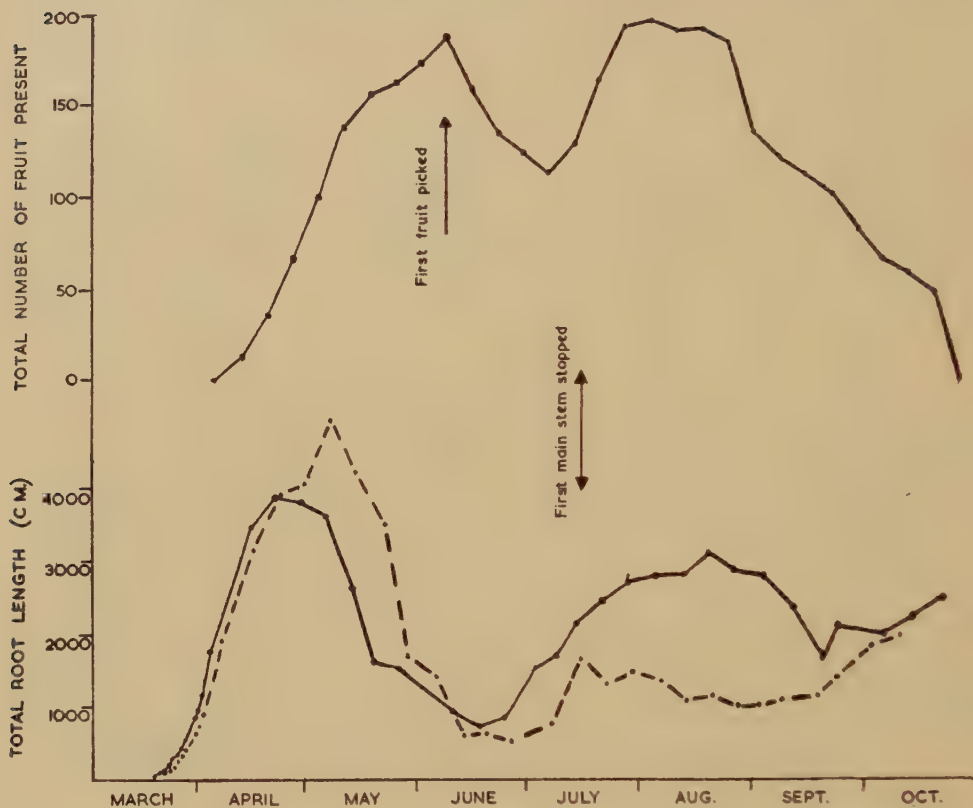


FIG. 2.

(Top) Total number of fruits present on four plants on north side of trench. (Bottom) Total length (cm.) of roots visible in glass wall of trench to north (continuous line) and south (broken line) of trench. Ailsa Craig, 1952.

grown under as closely similar environmental conditions as possible to those along the sides of the trench. From 19th April, as noted earlier, the box was placed permanently on an adjacent border. Soon after it had been lifted out of the trench, the number of roots observed through the two glass sides increased to such an extent that it became impossible to measure them all in the time available. This great increase in the amount of root seen was, however, transient and by 20th May a large proportion of the roots had died. On this date it was again possible to measure the roots visible in part of one of the glass faces. For this purpose three vertical panels, spaced at random across the glass face, were selected, occupying approxi-

mately a third of the total area. In the following week, on 27th May, and for the remainder of the season, it was possible to measure all the roots visible in the one face. Observations were not recommenced on the opposite side of the box until 10th July.

The results of the observations on the roots of the box plants are shown in Fig. 1. The graphs show the length of root visible on the two sides of the box. They are not complete for the reasons stated above, but where data are available the root growth on the two sides of the box shows close agreement.

The seasonal trend of root growth of the two rows of plants on opposite sides of the trench in the second year is shown in Fig. 2 (bottom). Both curves rose to a peak at closely similar rates, the peak being attained earlier and at a lower value by the roots on the north side, but the south side roots decreased more rapidly, so that at the subsequent trough approximately equal total lengths were visible. The overall trends in the root development of the two sets of plants are thus seen to be similar, though in the second half of the season, i.e. after stopping the stems, the size of the two root systems differ.

GROWTH OBSERVATIONS ON ROOTS AND SHOOTS.

The growth trends in the root systems noted above may now be discussed in more detail, in relation to the growth of the aerial organs.

Roots.

Total growth. The growth curve for the roots (Fig. 2, bottom) may be divided into five phases: I, for a fortnight from the time of the first observation of roots, i.e. until early April; II, thence until about the end of April; III, thenceforward until mid-June; IV, from June until the main stems were stopped in August; and V, until the end of the growing season.

In phase I the roots appear for a time to increase exponentially, but this soon gives place to II, which shows at first a constant high increment in total root length. This phase is suddenly interrupted and the increase in root length falls markedly, the maximum occurring at the end of April or early May. This is succeeded by III, a phase of reduction in total length due to the rapid death and disappearance of parts of the root system without replacement by new roots. The decline in the total length of roots is arrested in mid-June and the roots then increase (IV) to reach a second maximum which is maintained until early September with a final slight rise.

Growth of roots at different depths. The total root lengths observed at the north glass panel have been subdivided into those present in successive 10 cm. depth zones and the results shown in Fig. 3.

The greater percentage of the total root length at all stages of development occurs in the top four zones (0-40 cm.) comprising the loam soil; a considerably smaller proportion is found below this depth in the gravel subsoil, in which a consistent decrease in total length is observed with increasing depth.

At all depths the rise and fall in length of root is clearly seen, resembling the trend shown for the total root length (Fig. 2, bottom). It thus appears that the whole of the root system is affected and not just that at one or other depth.

It is important to note that, while roots were first seen at progressively lower depths on later dates, there is a relatively slight difference in the time of their appearance. At the sloping face of the box in the first year, only 20 days elapsed between

the appearance at the glass of the first roots and of those at the bottom of the box (at 80 cm. depth and vertically below the plants) ; in the second year, with a vertical glass panel in the trench a month elapsed (Fig. 3). Although there is this small lag with depth in first appearance, the curves show that roots are developing nearly at the same time at all levels and it is not the case that one level becomes largely occupied before development spreads to lower levels. This observation suggests that

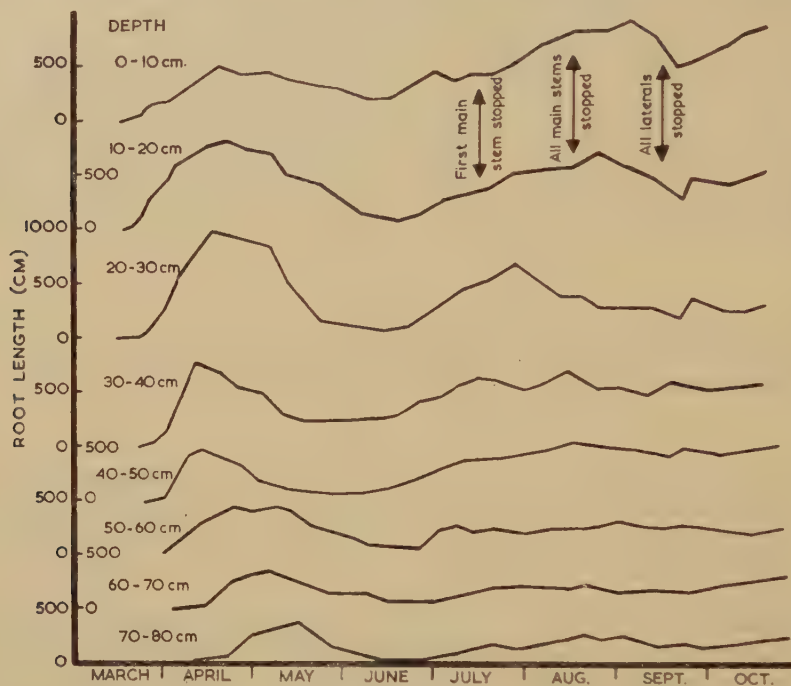


FIG. 3.

Total length (cm.) of roots, less than 1 mm. diam., visible in glass wall of trench in successive vertical horizons, 0-10, 10-20 cm., etc. Ailsa Craig, 1952. North side of trench.

the root system arising from the hypocotyl (of a transplanted tomato) reaches the lower depths within a short time, and then proceeds to ramify throughout the whole available soil. The initial peak of root development occurred at almost the same time in the top four horizons, i.e. down to 40 cm. depth, in the region of the transition from loam to gravel. At lower depths it occurred progressively later. Recovery from the low level of June took place at about the same time in all except the two lowermost horizons.

Shoots.

The growth of the aerial organs showed relatively simple trends and, in general, the trends of growth were similar in box and trench, in varieties and in the two years.

Stem. Fig. 4 shows the growth data for the north row of plants adjoining the trench in 1952. An exponential phase at the start of growth is followed by a steady rate until mid-May, when a transient reduction in growth rate for three or four weeks

appears, followed by a resumption of the previous rate of growth. The main stem of the first plant, that nearest the eaves, was stopped by removal of the growing point in early July and, as in turn the other plants reached the stage of stopping,

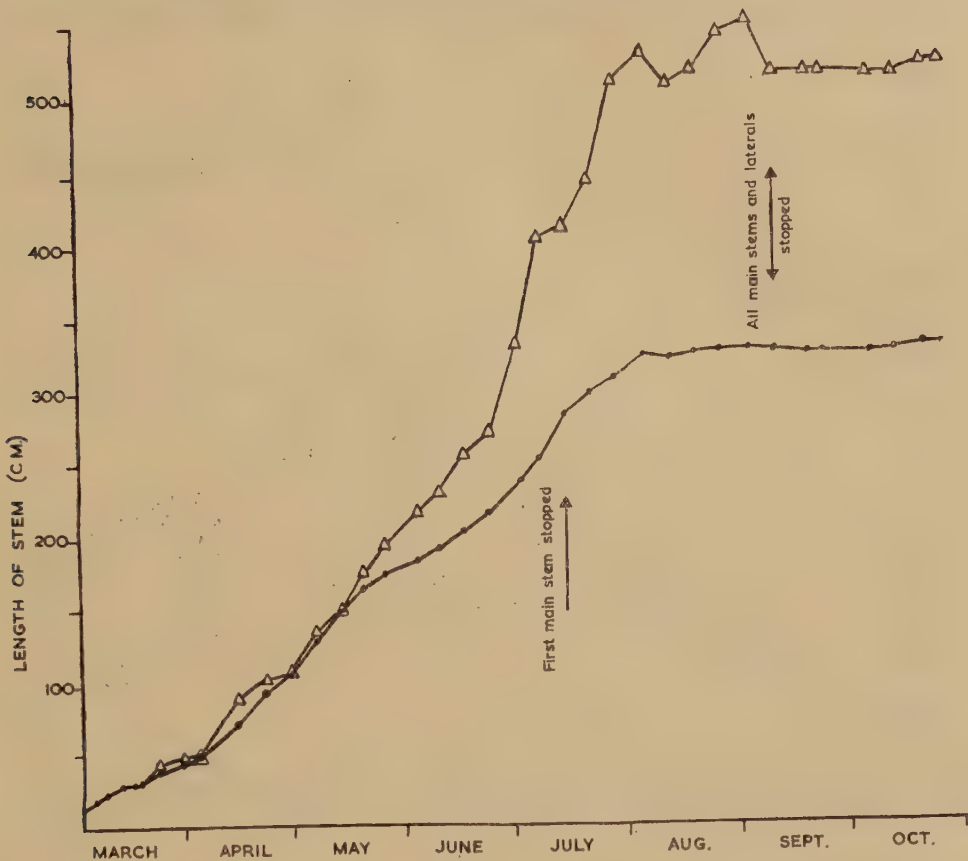


FIG. 4.

Mean length (cm.) of main stem (continuous line with dots) and main stem plus laterals (continuous line with triangles).

the mean value of stem length necessarily tended to a maximum. The growth curve for the whole plant (i.e. main stem plus laterals) is similar.

Leaves. In Fig. 5 are shown the curves of number of leaves *produced* and of leaves actually *present* at any time, expressed as means of the four plants. The trends of leaf production are seen to be closely similar to that of extension growth of the stem. The number of leaves present on the main stem reached a more or less constant plateau by mid-May. This difference between the curves of total number of leaves produced and those present at any time is in part artificial and due to the removal of the lower, yellowing leaves. The plateau of leaf number present on the main stem persisted until early August, after which, by continued

removal, the number of leaves present declined to a very few towards the end of the season.

During the course of the season's growth a very considerable number of axillary shoots were produced and removed after having produced up to nine leaves. This process was continued after the main stem and laterals had been stopped. These

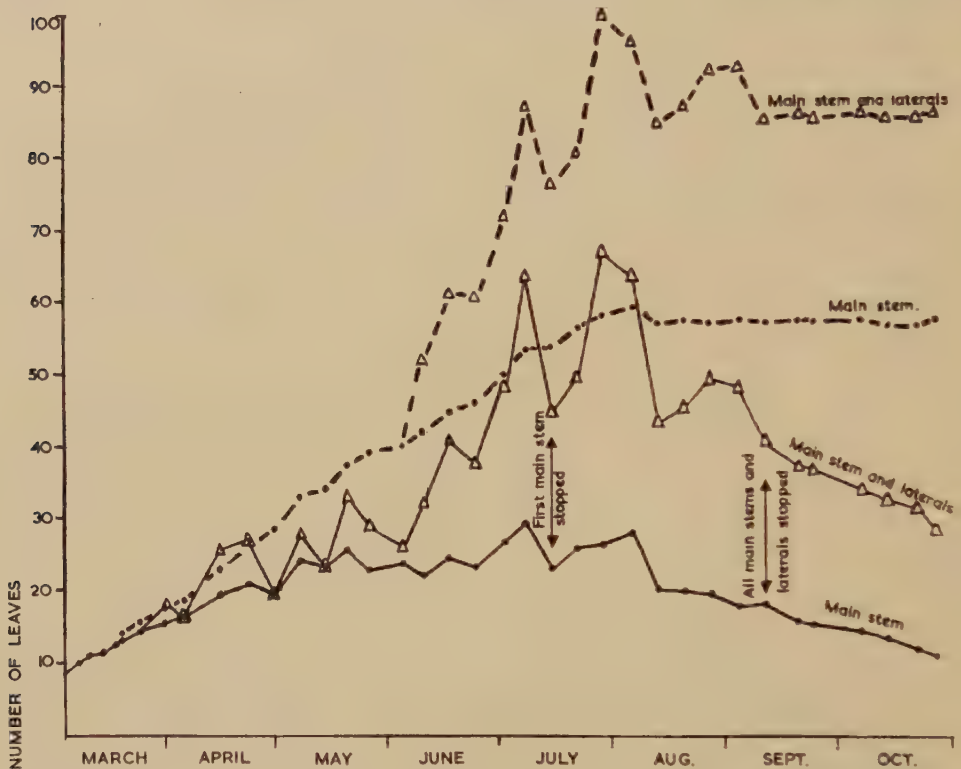


FIG. 5.

Mean number of leaves *present* on main stem (continuous line with dots) and main stem plus laterals (continuous line with triangles); mean number of leaves *produced* on main stem (broken line with dots) and main stem plus laterals (broken line with triangles).

ephemeral growths account in part for the irregular nature of the curves of Figs. 4 and 5.

Flowers and fruit. Fig. 2 (top) shows the number of fruits present on the plants in each week of the season, calculated from the dates of setting of the individual trusses and the date of picking of each fruit. The form of the curve is similar to that of the total root length. The interrelations of growth of the different organs are discussed below.

There are marked trends in time in the number and fate of the flowers in the different trusses. Fig. 6 shows the data obtained for Potentate (1951) and Ailsa Craig (1952) for the main stem trusses.

The first flower truss appeared soon after planting out (28th March 1951 ; 5th March 1952) when the plants had produced ten leaves. Thenceforward trusses were usually produced after every three leaves. The first trusses were setting a month later (26th April 1951 ; 15th April 1952). Fig. 6 (top) gives the total number of flowers produced per truss, plotted against the time of the first appearance of each

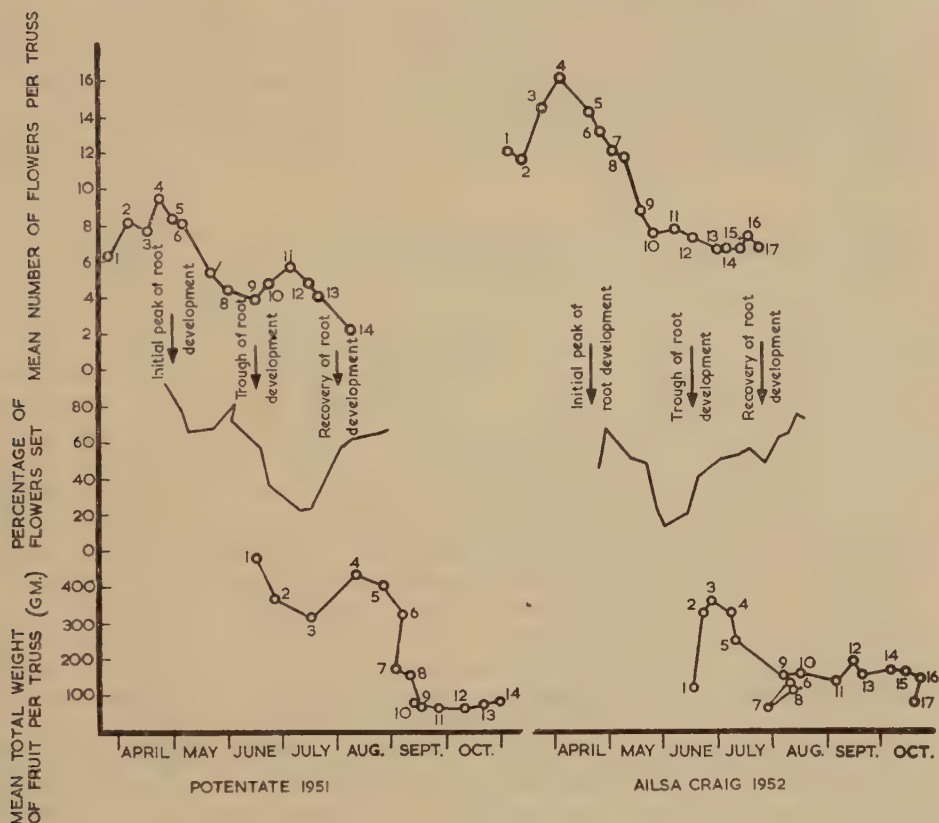


FIG. 6.

(Top) Number of flowers per truss in successive trusses (numbered). (Centre) Percentage of flowers set. (Bottom) Total weight (gm.) of fruit per truss picked from successive trusses. (Left) Potentate plants, 1951 ; (Right) Ailsa Craig, 1952, north side of trench. Arrows indicate phases of root development.

truss. This gives an estimate of the potential fecundity at different stages of growth.

The overall trend is seen to be a rise to a peak (at the fourth truss) in both years and with the two varieties, at the end (1951) or beginning (1952) of April, followed by a sharp decline to a much lower level during the period from the end of May until the main stems were stopped, i.e. when the fourteenth or seventeenth truss had been produced.

The fate of these flowers is illustrated in the central curves of Fig. 6. The percentages which set and developed fruit were at first fairly high (60-90 per cent. in

Potentate ; 45-70 per cent. in Ailsa Craig) but after the fifth or sixth truss there was a marked decline to a low value with a subsequent rise. The fall occurred at the beginning of June (1951) or end of May (1952) with recovery in mid-July (1951) or late June (1952). It was accompanied by a rise and subsequent fall in the percentage of flowers shed without setting, the remainder of the flowers being accounted for by the phenomenon of "dry set".

The bottom curves of Fig. 6 give the mean weights of fruit picked per truss. In both years these show two markedly distinct levels, high in the lower trusses (1-6 in Potentate, 1951 ; 2-5 in Ailsa Craig, 1952) with a steep fall to a low level in the later trusses (the bottom truss in the Ailsa Craig crop had a relatively poor set). The yield curves are thus largely a repetition, at a later date, of the number of flowers per truss.

INTERRELATIONS OF CHANGES IN GROWTH OF THE DIFFERENT ORGANS.

A general discussion of the growth trends appears premature on the data available. There is no evident relation between the growth trends of the aerial organs, or of the roots, and those environmental factors of which instrumental records were made. Between May and July, the main extension-growth period, there were only slight trends in maximum, minimum and mean day and night air temperatures, when expressed on a weekly basis, though there were short periods of high temperature. The weekly mean soil temperature at 10 cm. showed a slight fall over the first four weeks and then rose to a fairly steady value in mid-April, was maintained until the end of August, after which it fell to a lower level. Temperatures at greater depths did not show the initial fall but were otherwise similar, with reduced fluctuations. The period April to late June is one of increasing day-length, with slight reduction by the time stopping occurred.

While precise interrelations between the growth of the different organs of tomato plants must await further investigation, the present data, derived from plants under normal culture, indicate the following relations. Phase I (see p. 177), which shows exponential growth of the root system, continues until early April and is accompanied by a similar growth in the stem and by increasing size of the inflorescences as measured by flower number per truss. Between the beginning and middle of April, root growth rate is almost constant (II) and this is also true of stem growth. The first peak of root development is seen (Figs. 1, 2 and 6) to occur about the time at which the flowers in the first truss are set. A rapid death of roots now follows (III) and this in turn is accompanied by a rapid decline in the number of flowers per truss (Fig. 6), which continues until the beginning of June, after which truss size remains constant. This falling number of flowers per truss is reflected both in the percentage flowers per truss set and, later, in the weight of fruit per truss. The root length also reaches a minimum in June, followed by a renewal of root growth (IV). As shown in Figs. 1 and 2, this minimum in root development coincides in time with the first fall in number of fruits present, a fall which is due to the earlier fruits beginning to ripen and being picked.

The second rise in root development occurs during the time in which the fruit number is falling (Fig. 2) and the minimum in fruit number present on the plant marks the time at which the "first flush" in fruits has been removed, which occurs

early in July. The second rise in number of fruits carried by the plant is accompanied by the increasing root development. It is interesting to note that this increasing number of fruits present is not accompanied by a change in the number of flowers per truss, which remains constant, but is due to the increasing percentage of fruits set, which continues to rise as new fruits develop (Fig. 6).

The second rise in root development is not reflected in stem growth, but this may be due to the fact that by this time the plants have been stopped. The fall in number of fruits after mid-August can be fully accounted for by the stopping of the main stem so that no further trusses are produced. This is accompanied by the fall in root development (Phase V).

So far as leaf *production* is concerned this continues at an almost uniform rate until the time at which the main stem is stopped, but the number of leaves *present* on the plant, owing to the practice of removing senescent leaves, remains nearly constant over the period from early May to the end of July. Hence the assimilatory surface over the period during which the changes in root development, noted above, occur remains constant. It is, however, a well-established observation that wilting of the leaves occurs despite ample water supply during the period when the root development has now been shown to be minimal, so that it is possible that assimilation is reduced.

Phase I can be investigated only by the provision of a glasshouse allowing continued indefinite extension of the tops of the plants, which represents the tomato's natural habit. Possible effects of date of planting, involving consideration of day-length effect on the growth interrelations, will also require investigation.

Since observations of growth were made only at weekly intervals and the growth measurements themselves were relatively crude, short-term effects of environmental changes may well have been overlooked.

Earlier studies at Cheshunt of the seedling growth of tomatoes indicated a relationship between length of day, total accumulation of assimilate and its distribution (Bolas *et al.*, 1938 ; Goodall, 1945 and 1946) ; between length of day, water content and assimilation (Melville, 1937) ; and between length of day and assimilation rate (Goodall, 1945), resulting in changes in the relative proportions of root and shoot (Bolas and Selman, 1936 ; Goodall, 1945). There was a marked fall in the percentage gain in dry weight of the whole seedling plant between the beginning and end of May, with a recovery to the middle of June. This was accompanied by a similar trend in the percentage water content (Melville, 1937).

SUMMARY.

1. A preliminary survey of the roots of a row of tomato plants grown in a commercial glasshouse border under normal cultural practice determined the maximum depth reached towards the end of the season.

2. Tomato plants of two varieties were grown in glass-sided boxes and glass-lined trenches of this depth for successive years and observations made of the growth in length of the main stem and laterals, the number of leaves produced and actually present, the number of trusses in the successive phases of development and the total length of roots visible in the glass faces throughout the growth period, with observations on the environmental conditions. Commercial cultural practice was followed in respect of watering, fertilizer application, etc.

3. The validity of the glass panel observations as an estimate of the extent of the root system was examined by determining the amount of root present in blocks of soil adjacent to the glass. A high correlation was found.

4. The trustworthiness of the method for following the growth trend of the root system was tested by comparison of the total length of root visible on opposite sides of the row of plants in the box, and on the two sides of the trench, i.e. the root systems of two different rows of plants in the border. In both instances close agreement was seen in the quantity of root visible throughout the observations, except in the last stages of growth of the border plants.

5. The following major trends in growth were observed :

(a) The total length of roots showed a rapid rise to a peak in May, followed by an almost equally rapid fall until mid-June. There was then a recovery, the extent of which differed in particular cases, to a relatively steady level. The root length in successive depth zones followed the trend shown by the total throughout the season, and with the same relation in time to the different phases of development of the fruit trusses. This indicates that death of roots and production of new roots occurred in all parts of the root system.

(b) The main stem showed relatively steady growth from planting out until mid-May, when a reduction in growth rate occurred ; the original rate was resumed later and continued at the higher level until the main stems were " stopped ".

(c) The production of leaves followed closely that of stem growth increase.

(d) The number of leaves present on the main stem reached a steady value about mid-May, as a result of the removal of the yellowing lower leaves at about the same rate as the production of new ones. After the main stem was stopped in August, the number of leaves fell progressively.

(e) The total length of main stem and laterals showed a similar trend to that of the main stem, as did the sum of the number of leaves produced or present on these two types of growth.

(f) The number of flowers produced on the successive trusses showed two well-marked levels, high in the bottom six and declining to a low value in the ninth and uppermost. The flower trusses showed high percentage setting of fruit in the bottom five or six, with low set in the median seventh to ninth, and subsequent recovery. The weight of fruit picked, again, showed a marked separation into high values in the bottom five and a fall in the upper trusses.

6. The growth trends of shoots and roots, given above, bear no obvious relation to those environmental changes investigated. The only cultural treatment apparently influencing root growth was that of stopping.

The peak of root development coincided with the setting of the first trusses, the start of the recovery from the low level with the picking of these trusses, and the attainment of the final level with stopping of the main stem and laterals.

The root growth trends thus appear to be autogenous and to bear relation to the production and ripening of the trusses. Competition factors between trusses, stem and roots may be postulated as occurring, but it is not possible at present to decide the causal nexus involved.

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FURTHER OBSERVATIONS ON GROWTH AND UNION STRUCTURE OF DOUBLE-GRAFTED PEAR ON QUINCE

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IN 1948 an intensive investigation was begun (Herrero, 1951) to ascertain whether incompatibility could be forecast from the histological structure of the union in one- and two-year-old trees ; to what extent it might be diagnosed from detailed growth records made during the first two years ; and how far stock/scion incompatibility in double-worked trees might be modified by interactions between the top-scion and the intermediate. Herrero concluded that, for the three pear varieties which he examined, incompatibility was clearly shown in the union structure of two-year-old trees, that none of the growth records made during the first two years could serve as an indication of incompatibility, and that any effect of the top-scion on the compatibility between intermediate and rootstock was only slight, if it existed at all. Assessment of the ultimate compatibility status of the trees had to be made on the basis of experience gained from previous trials and, in the case of new and entirely untried graft combinations, on circumstantial evidence. It was therefore thought desirable to observe the behaviour of similar trees in a field trial. The present paper describes the growth of these trees and the final observations made on their union structure after nine years. Great variability developed between trees of the same graft combination and some of the problems arising from this are discussed.

MATERIAL AND METHODS.

Two pear varieties incompatible with quince rootstock, Clapp's Favourite and Williams' Bon Chrétien, and one compatible with quince, Beurré Hardy, were used in all the possible combinations of top-scion and intermediate in double-grafted trees on Quince B rootstock. The following key indicates the different graft combinations included in the trial :

Top-scion ..	H	H	H	C	C	C	W	W	W
Intermediate	H	C	W	H	C	W	H	C	W
Rootstock ..	QB	QB	QB	QB	QB	QB	QB	QB	QB

H, Beurré Hardy ; C, Clapp's Favourite ; W, Williams' Bon Chrétien ; QB, Quince B.

Since the rootstock was Quince B for all trees, the different combinations will hereafter be referred to by their top-scion and intermediate only.

All the trees had a three-inch intermediate stempiece and were double-grafted in one operation. The virus status of the trees was not known at the time of planting. It has since been found that the Quince B rootstock is uniformly infected with sooty

ring spot virus (Posnette, 1957) and that many trees in the trial also carried vein yellows. The possible implications of this will be discussed later. The trees were planted when two years old in a randomized block design with eight replications of each graft combination. They were pruned by a modified central leader system, and were supported by permanent upright stakes. Annual records were made of girth and crop weight, together with periodic descriptions of leaf colour, defoliation and suckering. Tree weights were recorded and the union structure was examined macroscopically when the trees were nine years old.

The unions were sawn longitudinally through the middle of the original whip and tongue graft and, after observation of the longitudinal section, the bark was peeled off one half of the trunk to expose the woody cylinder. The union in such a tree may be pictured as a slightly inclined plane. The quality of the union in the wood depends on the relative area with normal vascular connection compared to the area where the xylem of stock and scion are separated by a layer of non-lignified parenchymatous tissue. An estimate of the proportion of non-lignified tissue was made from observations along the circumference and across the line of union in the longitudinal sections. The results were summarized and finally expressed on a points system in five equal categories. The quality of bark union depends on the relative area of normal phloem and, to a lesser extent, of cortical connection compared to the area where such connection is interrupted by corky or necrotic tissues. It is believed that the extent of normal connection in the younger parts of the phloem, close to and adjoining the cambium, is of particular importance. An attempt was made to estimate this from macroscopic observations, aided by a hand lens, of longitudinal sections and bark peelings. Observations were again recorded on a points system in five equal categories, so that the best unions were evaluated at ten points (five each for wood and bark structure) and the worst at two.

A colorimetric starch test was made on five roots of each tree. Two roots from the largest and two from the smallest tree of each combination were fixed in formalin-acetic-alcohol and transverse sections of the roots were examined microscopically.

RESULTS.

Growth and cropping.

The final size attained by the trees is best shown by their weight at lifting, as follows:

Top-scion ..	H	W	H	W	C	C	W	C	H
Intermediate	W	W	C	C	C	W	H	H	H
Mean weight									
lb./tree ..	10.0	14.8	18.0	18.3	23.3	24.9	43.1	47.4	62.6
	Sig. diff. at $P=0.05$, 11.4.								

All graft combinations with the compatible intermediate Hardy made bigger trees than those with intermediates of either of the incompatible varieties Clapp's or Williams'. Although the combination H/H, with a compatible top-scion and intermediate, made larger trees than either C/H or W/H, with incompatible top-scions, this must be considered as due to the greater inherent vigour of the variety Hardy, rather than as an effect of compatibility. With the incompatible intermediates Clapp's and Williams', top-scions of Hardy made, on the contrary, exceptionally poor trees, indicating that the mere presence of a compatible top-scion does

not affect final tree size. The very poor growth of the inherently vigorous Hardy when grafted on Williams' or Clapp's intermediates suggests that this variety is more affected by an incompatible union below it, while the variety Clapp's is evidently the most tolerant as judged by the above figures. It is believed that this interpretation of the figures is justified as no evidence was found of incompatibility between top-scion and intermediate in any of the graft combinations.

Poor growth of incompatible trees has often been associated with excessive cropping, relative to tree size, early in the tree's life. This also occurred in the present trial. The cumulative crop of compatible and incompatible trees was approximately equal when the trees were seven years old. Thereafter the compatible trees carried increasingly larger crops as is shown by the cropping figures for the ninth year of the trial. These are given below :

Top-scion ..	H	H	C	W	C	W	H	C	W
Intermediate	W	C	C	W	W	C	H	H	H
Crop (lb./tree)									
in 1956 ..	4.8	7.9	14.7	18.2	18.8	21.8	25.9	30.1	41.9
		Sig. diff. at $P=0.05$, 11.9							

Trees with Hardy intermediates had a larger crop than those with other intermediates. This difference was significant at the 0.1 per cent. level for trees with Hardy and Williams' top-scions and at the 5 per cent. level for those with Clapp's. There was also a very highly significant difference in the fruitfulness of the three varieties used as top-scions as is shown by the following figures :

Top-scion ..	..	W	C	H
Mean crop lb./tree ..	..	27.3	21.2	12.9
		Sig. diff. at $P=0.05$, 1.44		

It is interesting that the proportion of wood parenchyma, as determined by Herrero (1951), for the stems of the three varieties differed in the same sense as their precocity, while the three varieties did not differ significantly in the percentage of vessels, rays or fibres in their stems. The percentage area of wood parenchyma in the stem was as follows :

W	C	H
15.1	11.3	9.9
	Sig. diff. at $P=0.05$, 3.49	

This observation is worth recording in view of a suggestion which has arisen from the anatomical work with apple rootstocks, that there may be some relationship between fruitfulness and the amount of wood parenchyma (Beakbane, 1952).

Other features that have been associated in the literature with incompatibility are breakage at the union, excessive suckering, unequal growth at the union, and poor leaf colour coupled with early autumn reddening and defoliation. Two trees broke at the lower union during the trial. They belonged to the combinations C/C and C/W and showed the characteristic type of smooth breaks that have long been associated with incompatibility. Suckering occurred to a greater or less extent in some trees of all combinations but not in those with Hardy intermediates or in any of the combination C/W. There was no evidence that overgrowth at the union could be correlated with incompatibility.

Records of autumn colouring were made from 1950 to 1955 in September or October according to the season. Although individual trees showed considerable

and unpredictable changes in their autumn colouring from year to year, some correlation between compatibility and autumn colour was clearly shown. Trees with Hardy intermediates had green foliage in autumn three times out of four, those with Clapp's or Williams' only once or twice in four seasons. The combination H/W was outstanding for its bright red autumn colouring.

Compatible and incompatible combinations differed in one other feature not previously recorded. This was the degree of variability between individual trees of the same combination. Using tree weight as the criterion, the following figures represent the ratio between the smallest and largest tree of each combination :

Top-scion ..	C	H	W	H	W	C	W	H	C
Intermediate	W	C	W	W	C	C	H	H	H
Ratio of smallest to largest tree ..	1:12	1:8	1:7	1:5	1:4	1:4	1:3	1:2.5	1:2

While some trees of incompatible combinations made almost no growth and at nine years old weighed only four pounds, the best trees in the combination W/W, W/C, C/C and C/W were as good as, and sometimes considerably better than, the worst W/H and C/H trees. The two best trees of the incompatible combination C/W compared favourably with the two smallest trees of H/H. This variability developed during the growth of the trees and could not have been forecast from any external observations made on the two-year-old trees.

Union structure.

The method of recording union structure, with a maximum of ten points for a perfect union, has been previously explained. On this basis the following results were obtained.

Union between top-scion and intermediate. These were nearly always in category 10, irrespective of the general state of the tree. Unions between different pear varieties were almost as good as those between grafts of the same variety. This confirms previous observations (Mosse and Herrero, 1951, Mosse and Scaramuzzi, 1956).

Union between intermediate and rootstock. The ratings were as follows :

Top-scion ..	H	C	W	H	W	C	C	W	H
Intermediate	W	W	W	C	C	C	H	H	H
Union structure ..	3.0	5.3	5.8	6.1	6.6	6.9	7.8	8.5	9.4
	Sig. diff. at $P=0.05$, 1.58								

A range of union structure was found in these trees, and the following points of interest arise :

1. Unions of Hardy/Quince B were better than those of Clapp's/Quince B, and Williams'/Quince B made the worst unions. The superiority of Hardy/Quince B unions was clearly forecast by the examination of two-year-old unions (Herrero, 1951).

2. In the nine-year-old trees the union between the intermediate and the rootstock was poorer in every instance when another variety was introduced as top-scion. This effect was significant at the 1 per cent. level when the combinations

H/H, C/C and W/W were compared with the rest. The union between Williams' and Quince B was markedly worse as a result of top-grafting it with Hardy.

3. Tree weight was correlated with union structure in trees with Williams' intermediates (correlation coefficient = +0.8349, $P < 0.001$) and less clearly so in trees with Clapp's intermediates (correlation coefficient = +0.5962, $P < 0.01$) while there was no suggestion of such a correlation in trees with Hardy intermediates (correlation coefficient = -0.1900, not significant).

Root structure.

Attention was concentrated on the starch content, the bark percentage in transverse sections (Beakbane, 1952) and the phloem structure of the roots.

Starch content. All roots examined had an adequate starch content when the trees were lifted in February.

Bark percentage. The bark percentage of Quince B roots of approximately one centimetre diameter was measured in eighteen trees belonging to nine different graft combinations. Trees from which root samples were taken were selected to represent the extremes of growth within each combination. The mean bark percentage of Quince B roots from individual trees varied from 25.2 to 44.2. The difference between roots from the two trees of a combination was in every instance greater than that between roots from the same tree. A variation of nineteen per cent. is considerably above the normal range of variation recorded for the root bark percentage of any single apple rootstock and there seems little doubt that the extended range was the result of incompatibility in some of the trees. The mean bark percentage for each graft combination is shown below. The difference between the bark percentages of the lightest and heaviest tree in each combination is given by the figures in *italics*.

Top-scion ..	H	W	C	W	C	H	C	W	H
Intermediate	W	C	C	W	W	C	H	H	H
Mean bark									
percentage	36.7	35.2	35.2	33.4	33.2	33.1	32.2	31.5	27.3
Difference be-									
tween light-									
est and									
heaviest tree	<i>15.0</i>	<i>2.9</i>	<i>2.9</i>	<i>6.7</i>	<i>2.9</i>	<i>4.4</i>	<i>1.2</i>	<i>-1.0</i>	<i>4.3</i>

Although the method of selecting the extremes, coupled with a rather limited replication, tends to mask differences between combinations, the figures show a marked tendency for Quince B under Hardy intermediates to have a lower bark percentage than under Clapp's or Williams' intermediates. This difference was significant at the 5 per cent. level. In eight trees out of nine the lightest tree within a combination had a higher root bark percentage than the heaviest, and this also was significant. In the combination H/W (the most incompatible by nearly all the criteria that have been considered) the difference was remarkably large. The figures support the findings of McKenzie (1956) that, within a given clone, a slow growth rate is accompanied by a tendency towards phloem rather than xylem production.

Phloem structure. The chief abnormalities that occur in the secondary phloem of unhealthy trees are early collapse and/or necrosis of sieve tubes, excessive cell division without proper differentiation (hyperplasia), apparent lack of contents or

abnormal staining reaction in the phloem parenchyma and sometimes ray cells, and occasionally necrosis of cells in the cambial region. Exact measurements of these characteristics are difficult, though it seems likely that the most useful single criterion, being the resultant of the two most important abnormalities (sieve tube collapse and hyperplasia), is the distinctness of individual radial files of phloem cells. With these criteria in mind sections were classified, without previous knowledge of their identity, into five groups, i.e. phloem structure very bad (1), bad (2), medium (3), good (4), very good (5). It was found that two roots from the same tree never differed by more than one category, and it is felt that this apparent constancy in phloem structure adds value to what is at present a purely subjective classification. The categories were given a numerical value according to the bracketed figures above. The results are arranged according to intermediates :

Top-scion	..	..	..	..	H	C	W	H	C	W	H	C	W	
Intermediate	..	..	..	..	W	W	W	C	C	C	H	H	H	
Evaluation of	{	of lightest tree			..	2	2	3	2	5	3	9	7	9
phloem structure in two roots		of heaviest tree			..	7	7	7	5	8	4	8	7	9

On the basis of these figures a highly significant correlation exists in trees with intermediates of Clapp's or Williams' between poor growth and abnormal phloem structure in roots. There was no such correlation in trees with Hardy intermediates. On the basis of their phloem structure, trees of the combination C/C were outstandingly good among the incompatibles and in this assessment the record agrees with that made of their union structure. The two records also agree in showing that structure was uniformly good in trees with compatible intermediates but varied from good to highly abnormal in the others; in suggesting that the introduction of a second variety as top-scion caused some deterioration, at least in the incompatibles; and in pointing to the combination C/H as the least satisfactory among the compatibles. This close similarity between records of union discontinuity and phloem structure of roots gives some hope that a method may be found of assessing union structure without destroying the tree.

DISCUSSION.

The observations made in this trial were of three distinct kinds : (1) growth records including girth, cropping, suckering, autumn colouring and final weight ; (2) examination of union structure ; and (3) observations on the starch content, phloem structure and bark percentage of roots. Before discussing their significance it may be helpful to summarize the findings. With two exceptions, viz. starch content of roots and overgrowth at the union, all the records demonstrated an obvious difference between the mean performance of trees with intermediates of the compatible variety Hardy and those of trees with intermediates of the incompatible varieties Clapp's and Williams'. The records demonstrated with equal clarity that individual trees of incompatible combinations were extremely variable and that the best ones were often better than the worst trees of compatible combinations.

Notwithstanding this, incompatible trees, owing to their unpredictable performance, must obviously be avoided in practice. The trial again demonstrated conclusively that incompatibility between pear and quince is due to inherent genetic factors causing some interaction between the tissues in contact, and it is for this

reason that the empirical method of double-working with a compatible intermediate is successful. The trial confirmed Herrero's suggestion (1951) that combinations requiring such double-working may be recognized by the structure of their union when two years old.

For those who seek a more fundamental understanding of incompatibility there remains the problem of the great variability of incompatible trees. Since all the rootstocks were infected with sooty ring spot virus and much of the graft wood of all three scion varieties was also infected with vein yellows, it is probable that some of the variation observed was due to virus infection (Posnette and Cropley, 1956a, 1956b). There is, however, no reason to suppose that virus infection of compatible and incompatible trees differed in kind or degree, whereas variability was much greater in trees of incompatible combinations. Unless, therefore, a specific interaction occurs between virus infection and the type of incompatibility here described—and there is at present no evidence to support such a suggestion—the greater variability of the incompatible trees cannot be attributed to virus, but must be regarded as an additional characteristic of incompatibility. The question arises, what constitutes an incompatible tree? Is it only the tree that grows badly, or the relatively uncommon tree that breaks at the union, or does it also include the tree of an incompatible combination which is growing well and, as experience has shown, may continue to do so throughout its life? With the increasing interest in the possible biochemical causes of incompatibility it is well that this question should be faced. Obviously the basic differences between the best and worst trees of an incompatible combination will be small, and furthermore they do not express themselves in growth differences during the first two years. It seems improbable that they are due merely to chance differences in grafting technique. Whatever their cause, it would seem that the incompatibility of many stock/scion combinations is marginal. Very small differences in environment, inherent constitution of the graft components or other as yet unrecognized factors are sufficient to account for the growth differences between an obviously incompatible tree and one that would be accepted as normal by the practical grower.

SUMMARY.

A nine-year-old incompatibility trial of double-grafted pears on Quince B rootstock is described, and the results are related to an earlier examination of similar two-year-old trees.

It is confirmed that incompatibility could not always be forecast from the growth of two-year-old trees, but that it was predictable from the structure of their unions. The union structure between pear intermediates and quince rootstocks was slightly worse if top-scion and intermediate were of different varieties, irrespective of the compatibility of the top-scion itself.

Abnormalities in the structure of the secondary phloem in the roots appeared to be closely associated with quality of the union, and this gives hope that a method may be found of assessing union structure without destroying the tree.

For all symptoms of incompatibility recorded there was a continuous range from horticulturally compatible to horticulturally incompatible combinations. It is suggested that great variability is a feature characteristically associated with incompatibility, and some of the difficulties arising from this are discussed.

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APPLE ROOTSTOCK STUDIES: THIRTY-FIVE YEARS' RESULTS WITH COX'S ORANGE PIPPIN ON CLONAL ROOTSTOCKS

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THE last report on this trial covered the first fourteen years (Hatton, 1935), and this paper presents growth and cropping data for a thirty-five year period, from 1922 to 1956 inclusive. The eleven rootstocks included in the trial were M.I, M.II, M.III, M.IV, M.V, M.VI, M.IX, M.X, M.XIII, M.XV and M.XVI. Five of these rootstocks that have been found to be of special value for fruitgrowing in England are discussed in greater detail. These are: M.IX, dwarfing; M.IV, moderately vigorous; M.I and M.II, vigorous; and M.XVI, very vigorous. The semi-dwarfing M.VII was not included in the trial. The number of trees employed is shown in Table I.

Plot history.

The trees were planted as maidens in February 1922, at 12 feet square, on a Plot comprising a sandy-loam soil belonging to the Malling Series merging into shallow and eroded phases of this Series (Furneaux, 1954). Each row consisted of alternate trees on two different rootstocks, except the two outside rows which comprised trees on three rootstocks. With the exception of the two central rows, whole rows of Cox alternated with pollinator rows of Stirling Castle. The variety Stirling Castle proved very susceptible to damage from the sprays used to control fungus diseases; consequently, during the period 1932-35, the Stirling Castle trees were systematically topworked or frameworked to Worcester Pearmain.

The Plot was thinned in 1943, leaving whole rows of Cox trees on one rootstock, with the exception of the two outside rows where trees on two rootstocks were left in each row. The trees that remained after thinning were tested during the period 1955-57 for rubbery wood and apple mosaic viruses. The double-budding method described by Posnette and Copley (1954) was used and the resulting scions were tested by the hand-bending method for rubbery wood (Prentice, 1950). These tests showed that all trees except one were free from these viruses. The exception was a tree on M.VI which was probably infected with rubbery wood virus, though this does not appear to have impaired its growth and cropping when compared with the remaining six healthy trees on this rootstock.

The trees were grown as open-centre bushes, spur-pruned with fairly hard leader-tipping. The plantation was clean cultivated, autumn weeds being allowed to grow, until spring 1954 when wild white clover (*Trifolium repens*) was sown and grass allowed to invade.

Soon after planting two trees died and one was damaged and had to be omitted from the trial; two of these were on M.VI and one was on M.X.

Owing to the susceptibility of Cox's Orange Pippin to Apple Scab (*Venturia inaequalis* (Cooke) Wint.) spraying was made an experimental issue on this Plot from 1926 onwards. Differential spray treatments were so arranged within trees on any one rootstock that pomological comparisons between trees on different rootstocks remained valid. These spray treatments and their results have been reported (Moore, 1930).

RESULTS.

A summary of the growth and cropping of trees on all eleven rootstocks is shown in Table I; also the number of trees before and after thinning, on which the mean figures in the other tables are based. The trial was not designed for statistical analysis, but the large number of trees planted on each rootstock had clearly shown the main contrasting differences in performance by the time the trees were thinned in 1943, at 22 years of age. Since the time of thinning, the trial should not be regarded as more than a demonstration of the major rootstock differences and the crop figures have, therefore, been separated into pre- and post-thinning periods in Table IV.

TABLE I.

Summary of growth and cropping of Cox's Orange Pippin on eleven clonal rootstocks.

Root-stock	Number of trees		Mean area trunk cross-section (sq. cm.) at 35 years	Total crop per tree (bushels*) at 35 years	Ratio of crop (lb.) to cross-section area (sq. cm.)
	Before thinning	After thinning			
M.I ..	16	8	174	28	6.5
M.II ..	16	8	319	59	7.4
M.III ..	16	4	159	23	5.8
M.IV ..	8	4	218	42	7.7
M.V ..	16	8	244	44	7.3
M.VI ..	14	7	240	36	6.1
M.IX ..	16	8	124	25	8.2
M.X ..	15	8	285	45	6.3
M.XIII ..	16	8	385	55	5.7
M.XV ..	8	4	452	42	3.7
M.XVI ..	16	4	444	62	5.6

* 1 bushel=40 lb.

Area of trunk cross-section.

The mean area of trunk cross-section of trees on four of the five main rootstocks at thirty-five years old agrees with the vigour groups into which they have normally fallen in other trials, viz. M.IX dwarfing, M.IV moderately vigorous, M.II vigorous and M.XVI very vigorous. The case of trees on M.I, normally classed as vigorous but here weaker than those on M.IV, is discussed later.

During the early years there were changes in the relative order of rootstocks for tree size (Table II) but since the fifteenth year the order has remained unchanged. Trees on M.IX have been the smallest throughout the trial and, for the first ten-year period, trees on M.IV were the largest, until they were overtaken by those on the very vigorous M.XVI. Between the tenth and fifteenth years, trees on the vigorous M.II also overtook those on the moderately vigorous M.IV.

The relative order of rootstocks for tree size was unaffected after the Plot was thinned and the percentage variability for trees on M.I, M.II, M.IX and M.XVI was reduced after thinning, but the variability on M.IV increased.

TABLE II.

Order of rootstocks for trunk cross-sectional area and accumulated crop per tree.

			Tree size (trunk cross-sectional area)				Accumulated crop					
Age			5	10	15	35	10	15	20	25	30	35
Smallest	..	..	IX	IX	IX	IX	XVI	XVI	I	IX	IX	IX
			I	I	I	I	II	I	IX	I	I	I
			XVI	II	IV	IV	I	IX	XVI	IV	IV	IV
			II	XVI	II	II	IV	II	II	XVI	XVI	II
Largest	..	..	IV	IV	XVI	XVI	IX	IV	IV	II	II	XVI

Height and spread.

There is good agreement in the order of rootstocks for area of trunk cross-section (Table II) and for area of branch spread (mean diameter squared), again with the exception of trees on M.I (Table III). The benefit from tree thinning is reflected in the increase in area of spread recorded in the thirtieth year, particularly with trees on the more vigorous rootstocks; by the thirty-fourth year, however, overcrowding was again becoming serious, and the reduced figures indicate that "siding up" of some of the more spreading branches had become necessary.

TABLE III.

Tree height (m.) and area of spread (sq. m.).

Age	10		15		30		34	
Rootstock	Height	Area	Height	Area	Height	Area	Height	Area
M.IX	2.3	3.6	2.4	10.2	2.7	10.2	2.9	9.6
M.IV	3.3	7.8	3.5	15.2	3.4	16.0	3.3	10.8
M.I	2.8	4.4	2.9	9.6	3.0	14.4	3.1	11.5
M.II	3.1	6.2	3.7	16.8	3.6	24.0	3.9	21.1
M.XVI	3.5	6.7	4.6	21.1	4.6	40.9	4.9	30.0

Accumulated crop per tree.

By the fifth year only trees on M.IX had yielded any fruit at all and by the tenth year these had yielded most fruit and trees on M.XVI least. The changes in the relative order of rootstocks for accumulated crop are recorded in Table II. The precocious trees on M.IX were overtaken by the fifteenth year by trees on M.IV which were then overtaken by trees on both M.XVI and M.II in the twenty-fifth year. Trees on M.XVI finally overtook those on M.II in the thirty-second year. Whereas it took twelve years for trees on M.II to overtake those on M.IX, it took eighteen years for trees on M.XVI to accomplish this.

The accumulated yield for trees on all rootstocks in the trial is shown in Table I. In Table IV the total crop for trees on the five important rootstocks has been separated into two periods which cover that before and that after the Plot was thinned. The period from the twentieth to the twenty-fifth years, when the trees were severely overcrowded and then recovering from thinning, has been omitted. On this basis the thinning did not affect the relative order of rootstocks for total crop (Table IV) when compared with that for accumulated crop up to the thirty-fifth year (Table II).

The heaviest crop per tree was carried in the twenty-sixth year (Table IV), the small trees on M.IX carrying over two bushels of fruit per tree and the very vigorous trees on M.XVI more than seven bushels.

TABLE IV.

Total crop in lb. per tree to 20th year (before thinning) and from 25th to 30th year (after thinning).

Rootstock	M.XVI	M.II	M.IV	M.I	M.IX
Total crop before thinning	461	607	622	339	345
" " after	1,536	1,265	765	547	486
Heaviest crop (lb., in 26th year)	299	259	162	104	100

Fruit size.

Mean fruit size has been summarized for the period 1942-52 (Table V), but excluding 1944 when late spring frost damaged the crop.

TABLE V.

Fruit size ; mean weight per 100 fruits (lb.).

Rootstock	M.IX	M.IV	M.II	M.XVI	M.I
Mean for 1942-52, excluding 1944 ..	21.2	20.1	18.9	18.9	17.6

During this ten-year period, when the trees may be considered fully mature, those on M.I consistently bore smaller fruits than did trees on the other four rootstocks, those on M.IX bearing the largest fruits both before and after the trees were thinned. Trees on M.II and M.XVI bore fruits that were as large as those from trees on M.IV in the post-thinning period although M.IV had borne the larger fruits before thinning. In 1949, a year of severe summer drought, trees on M.IV yielded the largest fruits, those from trees on M.IX and M.XVI being slightly smaller ; the smallest fruits were again borne by trees on M.I while fruits from trees on M.II were only slightly larger.

Ratio of crop to tree weight.

The ratio of total crop to weight of trunk and branches on those trees that were grubbed at twenty-two years of age shows that trees on the dwarfing and productive

M.IX had yielded eight times their own weight in fruit whereas trees on the very vigorous M.XVI had yielded less than twice their weight (Table VI).

TABLE VI.

Ratio of total crop to weight of trunk and branches ; trees 22 years old.

Rootstock	M.XVI	M.II	M.IV	M.I	M.IX
Number of trees	12	8	4	8	8
Area trunk cross-section (sq. cm.) ..	265	186	170	88	70
Weight of trunk and branches (lb.)	329	165	158	57	50
Ratio of total crop to tree weight ..	1.8	4.8	5.4	7.0	8.3

The order of rootstocks for total tree weight is identical with that for area of trunk cross-section in the year of grubbing, although the range for tree weight (XVI/IX=6.58) is considerably greater than that for area of trunk cross-section (XVI/IX=3.78) (Table VI).

Crop in relation to tree spacing.

An estimate of the spacing at present required by trees of Cox's Orange Pippin on four rootstocks *on this Plot* is shown in Table VII. On a deeper soil, or in an area of greater rainfall, trees on M.IX and M.IV might not need further room whereas it is almost certain that trees on M.II and M.XVI would have to be spaced wider apart.

TABLE VII.

Estimated cumulative yields per acre in bushels (40 lb.) at appropriate spacing for trees on four clonal rootstocks.

Rootstock	Distance apart in feet	Number of trees per acre	10 years	20 years	30 years
M.IX	12	302	392	2,604	6,613
M.IV	17	150	142	2,332	5,351
M.II	20	108	97	1,638	5,140
M.XVI	24	75	20	864	3,523

There is good agreement in the order of rootstocks between these trees of Cox's Orange Pippin and those of Lane's Prince Albert at the same spacing and at similar periods of development (Preston, 1958), with the exception of trees of the latter variety on M.IV which overtook those on M.IX after the first ten-year period.

It remains to be seen whether trees on the very vigorous M.XVI will eventually outyield, on an acreage basis, those on the dwarfing M.IX. Considering each period separately, trees on the latter rootstock had yielded, during the second ten-year period from planting, 162 per cent. more fruit than had those on the former, but during the third ten-year period this lead had been reduced to 50 per cent.

DISCUSSION.

The position of Cox's Orange Pippin as a commercial variety thirty-five years ago should be borne in mind in assessing the results from this trial. When the trial was planted, growers in many areas considered the variety unprofitable to plant. It is highly susceptible to Apple Scab and the lesions caused by this fungus on the wood often provided a means of entry for Apple Canker (*Nectria galligena* Bres.). No suitable spray programme for Apple Scab had been devised and the sprays used, especially Bordeaux mixture, often caused severe leaf scorch and leaf and fruit drop. Furthermore, the pruning of this variety was not fully understood, although in this trial spur pruning was practised deliberately in order to produce shoot growth which was the main record of vigour then used. This resulted in trees on the more vigorous rootstocks being pruned too hard by present-day standards; it is hardly surprising, therefore, that trees on the dwarfing M.IX were the only ones to yield a *total crop* of a bushel of fruit per tree by the tenth year. Once the larger trees began to settle down under the steadily improving cultural conditions, yields increased and, since the twentieth year, trees on the popular M.II have averaged annually over 300 bushels per acre. That Cox's Orange Pippin is now the leading high quality dessert variety grown in England, and in many other European countries as well, is largely the result of collaborative work of pomologists, plant pathologists and spray chemists, which has made commercial production of this variety economically possible.

The relative order for tree size for Cox on the five rootstocks, M.I, M.II, M.IV, M.IX, and M.XVI, was established by the fifteenth year. This is in agreement with that for trees of Lane's Prince Albert on the same rootstocks (Preston, 1958). The order for cropping was established by the twenty-fifth year, with the exception of trees on the very vigorous M.XVI which did not overtake those on M.II until the thirty-second year. The Lane's trees established their order for cropping by the twentieth year. This disparity between the two scion varieties is almost certainly due to the hard pruning of the Cox trees which delayed their maturity, especially those on vigorous and very vigorous rootstocks—more so than with Lane's, a variety that is more tolerant of hard pruning, even in the early years. There is now ample evidence to show that persistent leader tipping and spur pruning delays bearing with Cox's Orange Pippin (Grubb, 1932; Preston, 1954), and that it is possible to bring trees of this variety on very vigorous rootstocks, such as M.XVI, into bearing as quickly and almost as heavily as trees on the dwarfing M.IX by using lighter methods of pruning (Preston, 1953).

The trees in this trial were very variable, mainly because of their position in relation to soil depth. This is to some extent substantiated by the behaviour of trees on M.XVI, which were the least variable of the five rootstocks, since trees on this rootstock occurred in the two adjacent central rows. Nevertheless, the data show clearly the predominant position, among the Malling clones, of M.II as an all-round rootstock for Cox; other field trials have also shown its suitability to a wide range of soil conditions (Hatton, 1926; Rogers, 1946). Trees on M.I, however, have shown themselves over many years, and in different parts of England, to be intolerant of shallow soils and drought conditions, and the poor behaviour of M.I in this trial can probably be accounted for by the shallow soil overlying the Kentish Ragstone rock. Before thinning, half of the trees on M.I were known to be on a very shallow area of soil but the trees remaining after thinning, which were on a deeper soil, were

also poor and stunted. The occurrence of ten dry years out of thirty-five, seven of which included severe summer droughts, may also have contributed to the poor performance of this rootstock. Trees on M.XIII have also been found to be unsuited to these conditions, especially in Eastern England (Dorey, 1949), but their behaviour in this trial has been better than that of trees on M.I, though inferior to that of trees on M.II (Table I).

Of the six other rootstocks included in the trial, M.III, M.V, M.VI, M.X, M.XIII and M.XV, none has equalled the general performance of M.IX, M.IV, M.II and M.XVI when comparisons are made within the same vigour group.

SUMMARY.

The growth and cropping of Cox's Orange Pippin apple on eleven clonal rootstocks up to thirty-five years of age are reported. Trees on M.I, M.II, M.IV, M.IX and M.XVI are dealt with in detail.

The relative order for tree size on the five main rootstocks was established by the fifteenth year and this agreed with results reported earlier for Lane's Prince Albert on the same rootstocks. The order for cropping was established by the twenty-fifth year, with the exception of trees on the very vigorous M.XVI, the hard pruning of this variety having delayed the onset of bearing with trees on vigorous and very vigorous rootstocks.

Trees on the dwarfing M.IX yielded the heaviest accumulated crop during the early years but they were superseded by trees on the moderately vigorous M.IV by the fifteenth year, these trees in turn being superseded by those on the vigorous M.II by the twenty-fifth year. Trees on M.II were eventually surpassed by those on the very vigorous M.XVI by the thirty-second year. The heaviest annual yield was recorded in the twenty-sixth year. The yields are discussed in relation to tree spacing.

The ratio of total crop to weight of trunk and branches on trees grubbed at twenty-two years of age showed that those on the dwarfing M.IX had yielded eight times their own weight in fruit, whereas trees on the very vigorous M.XVI had yielded less than twice their own weight.

The cultural requirements of this difficult dessert apple were not thoroughly understood during the early years of the trial, consequently trees on M.IX were the only ones that had yielded a total crop of a bushel per tree by the tenth year. Under improved cultural conditions trees on M.II have, since the twentieth year, averaged annually over 300 bushels per acre and this rootstock has given a good all-round performance with Cox's Orange Pippin.

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THE EFFECT OF SOIL MOISTURE ON THE MINERAL COMPOSITION OF APPLE PLANTS GROWN IN POTS

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ORCHARD management trials, at present in progress at East Malling, show that the mineral composition of the leaves of apple trees growing under a straw mulch differs significantly in many respects from that of leaves from similar trees growing in grass or in cultivated soil. The effect is believed to be due in part to the moist conditions which are maintained in the soil under mulch.

A consideration of published work upon the effect of moisture on the mineral composition of various fruit and other plants has revealed serious discrepancies in the data from different sources. Williams and Shapter (1955) grew barley and rye in pots containing a mixture of loam and sand, half of which were watered frequently and the other half intermittently ; they found that the low water treatment increased the percentage of potassium, calcium and magnesium but reduced that of phosphorus in the plants. Iljin (1954), commenting on the composition of plants grown on dry sites, says that they contain a higher concentration of nitrogen, potassium and calcium, but he noticed that flooding increased the potassium level in plants sampled late in the season. According to Sheets *et al.* (1955) the concentration of phosphorus in turnip greens was increased and that of calcium decreased by irrigation. Emmert (1936), working on tomato plants in a greenhouse, showed that under moist conditions less potassium and more phosphorus could be extracted from petioles by dilute acetic acid. El Tomi and Wolfe (1955) found that irrigation significantly lowered the concentration of nitrogen in the leaves of young orange trees and this is supported by the results obtained by McMurtrey *et al.* (1947) who compared the composition of leaves from tobacco plants grown under dry and irrigated conditions. The leaves of plants which received water contained less nitrogen but more potassium per cent. of dry matter. Janes (1948) found that heavy irrigation, when applied to snap beans in the field, significantly reduced nitrogen and phosphorus but increased the potassium concentration in the plants.

This lack of unanimity in the results of the work cited, which is no doubt due to the widely different growing conditions and the range of crops used, emphasizes the need for experimental data on the mineral composition of apple plants as affected by soil moisture conditions. This question is difficult to investigate with mature trees in the field (though attempts to do so are being made at East Malling) ; hence a pot experiment with apple rootstocks was decided upon because the soil moisture conditions can be controlled readily within tolerable limits, and the leaves, shoot and root of the plant may be examined for mineral content. Such information is useful for interpreting and understanding the field performance of trees under

various orchard management systems, though caution is always necessary when applying to field conditions results which have been obtained with potted plants.

Experimental material.

One hundred layered M.VII rootstocks were examined and sixty-four of them selected for uniformity, particularly with regard to root system. After trimming the stems to about eight inches and the roots to two inches, the rootstocks were weighed, labelled and planted in $7\frac{1}{2}$ -inch pots in John Innes No. 1 compost on 1st March 1955. The pots were plunged in soil and covered with straw until mid-May when they were removed into an unheated greenhouse for fourteen days because growth was rather slow. Leaf buds were pinched out at an early stage and only two shoots were allowed to develop from the stock. After a further week in the open, thirty plants were finally selected to receive the treatments. At the same time five were sampled to give the initial composition of the plant parts.

Treatments.

At the commencement of treatments on 7th June all plants were placed under a glass canopy with open sides, though some glass protection was given against driving rain from the south and west. All pots were stood in 2-in. deep saucers which were painted with bitumastic paint to render them non-porous and the plants were randomly allocated, fifteen to each of the two treatments.

All pots were brought to field capacity initially and thereafter the "wet" treatment consisted of watering to field capacity daily with soft water. The small excess of water which drained into the saucer was subsequently reabsorbed. In the "dry" treatment water was withheld until signs of incipient wilting appeared and then the pots were watered to field capacity. Detection of the incipient wilting point was aided by using a soil moisture tensiometer in one of the discarded pots containing a rootstock, and also by observing potato plants grown under similar conditions in $7\frac{1}{2}$ -inch pots. When the potatoes were severely wilted the tip of the apple plant was not quite erect and at this point water was applied. A further check on loss of water was maintained by periodically weighing the potted plants.

Uniform applications of dried blood were made to all pots on 9th and 24th June to ensure that plants did not suffer from nitrogen deficiency.

Sampling.

After six weeks of treatment, on 19th July, five plants from the "wet" and five from the "dry" treatments were harvested. The remainder were harvested after approximately thirteen weeks, on 8th September.

At each harvest the soil was washed off the roots which were separated as one sample, other samples consisting of the old stock, the whole of the two new stems, the leaves from the top third of the two new stems, the leaves from the middle third and the leaves from the basal third of the two new stems. Fresh weights, dry weights and total nitrogen, phosphorus, potassium, calcium and magnesium were determined for each sample by reliable small-scale chemical methods.

Measurements of total length of new shoots on each plant were made at weekly intervals.

RESULTS.

The growth curves for total shoot length of plants under the "wet" and "dry" treatments were both quite smooth. Differences in extension growth were first detected three weeks after the treatments were started and, by the final harvest, the average length of new shoot was 211 cm. for the "wet" treatment and 118 cm. for the "dry".

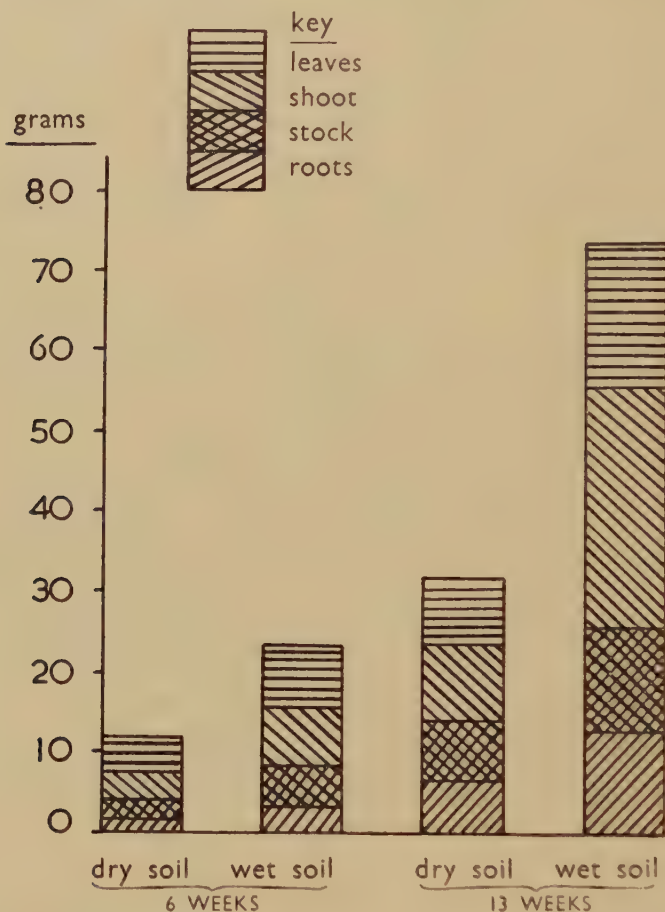


FIG. 1.

Increase in dry matter in various parts of potted apple trees after 6 weeks and 13 weeks of the two treatments.

On 2nd July it was noticed that either one or both shoots of four plants under the "wet" treatment had stopped growing and, although they started to grow again later, they obviously behaved differently in the remaining period of the experiment. It was suspected that they had become waterlogged because the excess of water which drained into the saucers usually was not reabsorbed. When these plants were

eventually harvested the lower half of the root system of each was found to be dead. This unforeseen loss of plants made it impossible to take three harvests as originally planned ; so, while the first harvest on 19th July consisted of five plants from each treatment, the second one on 8th September consisted of ten plants from the " dry " and six from the " wet " treatment. The four waterlogged plants were analysed chemically and, although the results are not given in this paper, they behaved as though an intermediate treatment had been applied.

The total amount of dry matter produced in the whole plant and in all its parts was significantly greater ($P < 0.001$) under the " wet " than under the " dry " treatment, whether the plants were harvested in July or in September, and the new

TABLE I.
Effect of soil moisture on percentage of elements in dry matter.

Element	Time of sampling	Plant part	Treatment		Confidence level, <i>P</i> less than
			Dry	Wet	
Nitrogen	July after 6 weeks	Middle leaves	3.09	2.14	0.01
		All the leaves	3.06	2.34	0.01
		Whole plant	1.55	1.15	0.001
	September after 13 weeks	Middle leaves	2.59	2.16	0.01
		All the leaves	2.53	2.30	N.S.
		Whole plant	1.32	1.04	0.001
Phosphorus	July after 6 weeks	Middle leaves	0.18	0.23	N.S.
		All the leaves	0.19	0.23	0.05
		Whole plant	0.11	0.13	N.S.
	September after 13 weeks	Middle leaves	0.12	0.23	0.001
		All the leaves	0.13	0.23	0.001
		Whole plant	0.09	0.14	0.001
Potassium	July after 6 weeks	Middle leaves	1.86	2.63	0.01
		All the leaves	1.77	2.26	0.01
		Whole plant	0.94	1.16	0.001
	September after 13 weeks	Middle leaves	1.66	1.90	0.01
		All the leaves	1.59	1.82	0.01
		Whole plant	0.72	0.83	0.01
Calcium	July after 6 weeks	Middle leaves	1.01	1.37	0.01
		All the leaves	1.07	1.35	0.01
		Whole plant	0.69	0.73	N.S.
	September after 13 weeks	Middle leaves	1.12	1.27	0.05
		All the leaves	1.09	1.20	N.S.
		Whole plant	0.58	0.62	N.S.
Magnesium	July after 6 weeks	Middle leaves	0.20	0.24	N.S.
		All the leaves	0.20	0.21	N.S.
		Whole plant	0.11	0.12	N.S.
	September after 13 weeks	Middle leaves	0.18	0.20	N.S.
		All the leaves	0.18	0.21	0.05
		Whole plant	0.09	0.10	0.05

N.S., not significant.

shoots gained proportionately more than the other parts (Fig. 1). The effects of treatments on the concentrations of the five elements N, P, K, Ca and Mg in the whole plant and in its parts are shown in Tables I and II for the two harvests. Statistical significance levels have been calculated only for those results which are of particular interest in connection with the foliar diagnosis of nutritional status. Though the full data are available for the other plant parts they have not been analysed statistically and only the mean values are given.

The total quantity of each element in every plant part was calculated from the determinations of amounts of dry matter and of the concentrations of the respective elements. The results for the September harvest are expressed in the form of a series of histograms in Fig. 2.

TABLE II.
Effect of soil moisture on percentage of elements in dry matter.

Element	Plant part	At start in June	July		September	
			Dry	Wet	Dry	Wet
Nitrogen	Leaves, top	4.56	3.42	2.65	2.70	2.62
	" middle	4.50	3.09	2.14	2.59	2.16
	" bottom	4.00	2.62	2.32	2.26	1.87
	Shoots	1.78	1.10	0.71	0.97	0.53
	Stock	0.63	0.71	0.47	0.68	0.46
	Roots	2.04	1.56	1.18	1.40	1.21
	Whole plant	1.48	1.55	1.15	1.32	1.04
Phosphorus	Leaves, top	0.39	0.28	0.34	0.16	0.26
	" middle	0.32	0.18	0.23	0.12	0.23
	" bottom	0.28	0.14	0.16	0.11	0.20
	Shoots	0.17	0.09	0.08	0.09	0.10
	Stock	0.11	0.05	0.07	0.06	0.09
	Roots	0.20	0.13	0.16	0.10	0.21
	Whole plant	0.15	0.11	0.13	0.09	0.14
Potassium	Leaves, top	1.69	1.85	2.83	1.62	1.89
	" middle	1.71	1.86	2.63	1.66	1.90
	" bottom	1.50	1.52	1.65	1.40	1.64
	Shoots	1.57	0.71	0.79	0.46	0.47
	Stock	0.35	0.39	0.47	0.35	0.35
	Roots	1.95	1.17	1.32	0.64	0.86
	Whole plant	0.86	0.94	1.16	0.72	0.83
Calcium	Leaves, top	0.56	0.71	0.83	0.77	0.94
	" middle	1.18	1.01	1.37	1.12	1.27
	" bottom	2.02	1.45	1.58	1.40	1.46
	Shoots	0.63	0.47	0.51	0.41	0.39
	Stock	0.51	0.54	0.43	0.40	0.46
	Roots	0.70	0.65	0.53	0.50	0.57
	Whole plant	0.61	0.69	0.73	0.58	0.62
Magnesium	Leaves, top	0.16	0.20	0.25	0.21	0.27
	" middle	0.21	0.20	0.24	0.18	0.20
	" bottom	0.39	0.21	0.16	0.16	0.14
	Shoots	0.15	0.09	0.08	0.06	0.06
	Stock	0.04	0.05	0.05	0.04	0.05
	Roots	0.14	0.15	0.14	0.08	0.11
	Whole plant	0.19	0.11	0.12	0.09	0.10

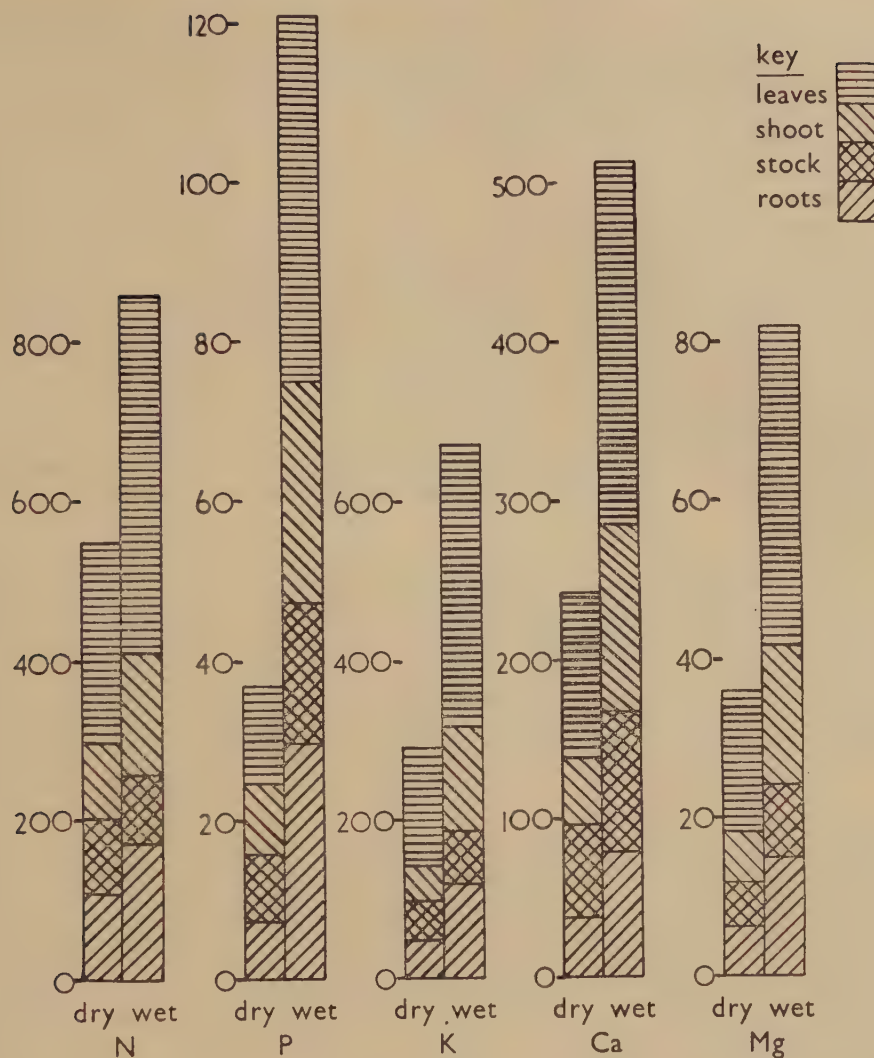


FIG. 2.

Total amounts of each element, expressed as milligrams, in different parts of potted apple trees after 13 weeks of the two treatments.

Nitrogen.

As shown in Table I, the "wet" treatment very significantly reduced the concentration of nitrogen in the whole plant after six weeks and the difference was maintained throughout the growing season. There were similar differences for the middle leaves and for all the leaves. Between July and September there was a fall in concentration of the element in all parts of the plant, except the stock, when grown under the "dry" treatment (Table II); under the "wet" treatment there was only a suggestion of a fall in concentration in the whole plant, and that was

mainly due to differences in the new shoot and the bottom leaves. From Fig. 2 it may be seen that the total quantity of nitrogen in the plant was much greater under the "wet" treatment in spite of the reduction in concentration, and the same applied to all parts of the plant except the old stock, which contained almost the same total amount of nitrogen under both treatments.

Phosphorus.

By September the concentration of phosphorus in the whole plant and in the leaves was very significantly greater under the "wet" treatment than under the "dry", an effect which was barely apparent after six weeks of treatment. From the beginning of treatments early in June to September there was very little change in the concentration of phosphorus in the whole plant under the "wet" treatment (from 0.15 per cent. at the start to 0.13 in July and 0.14 in September) but under the "dry" treatment there was a continuous fall in concentration in most parts of the plant (Table II). The total quantity of phosphorus in the whole plant under the "wet" treatment was more than three times that present under the other treatment (Fig. 2), the roots and leaves making the largest contribution to this effect.

Potassium.

At both sampling dates the concentration of potassium in the whole plant and in the leaves was significantly greater under the "wet" treatment, the effect being greater in July than in September (Table I). From June to July the concentration of the element increased in the whole plant but decreased in the shoot and the root, and then from July to September the concentration decreased in all parts of the plant (Table II). The "wet" treatment more than doubled the total quantity of potassium in the whole plant, the part least affected being the stock.

Calcium.

The concentration of calcium in the whole plant was increased slightly but not to a significant degree by the "wet" treatment, though the concentration in the middle leaves was significantly increased. The changes in concentration of the element as the season progressed were small for the whole plant and for most of its parts. In the top leaves it increased progressively, whereas in the bottom leaves and the shoot it decreased progressively, both effects being emphasized by the "wet" treatment. The total quantity of calcium in the whole plant was much greater under the "wet" than under the "dry" treatment.

Magnesium.

There was a tendency for the "wet" treatment to increase slightly the concentration of magnesium in most parts of the plant, though in the bottom leaves, which formed the main exception, this tendency was reversed. Treatments greatly affected the total amount of the element in the plant, as shown by Fig. 2.

DISCUSSION.

In carrying out the experiment an attempt was made to isolate so far as possible the direct effect of soil moisture on the uptake and distribution of the major nutrient

elements in the apple plant. The John Innes compost was well supplied with nitrogen, phosphorus and potassium (Lawrence and Newell, 1948), and extra nitrogen was added in the form of dried blood as a top dressing. Leaching of nutrients was prevented by avoiding drainage to waste, and the plants were watered with de-ionized water drawn from carboys, the temperature of which was approximately the ambient temperature of the pots. Thus it is probable that the only secondary factor which might have entered into the treatments was that due to differential microbial activity in the soil. Since the phosphorus and potassium were present in the compost as inorganic salts it is unlikely that their availability would have been affected by microbial activity; on the other hand the bulk of the nitrogen was present in an organic form and its availability to the plant was therefore more dependent on microbial activity, which in turn is correlated with soil moisture.

Richards and Wadleigh (1952) state that nitrification is most active at a moisture content near to field capacity. This being so, it might be expected that nitrogen would be more readily available to the plant under moist conditions and that the concentration of the element in the whole plant would be increased where water was applied frequently. In fact the percentage of nitrogen in the dry matter of the whole plant was significantly reduced from 1.32 to 1.04, though the actual quantity of nitrogen was increased (Fig. 2), which means that the rate of increase in dry matter of the plant was greater than the rate of uptake of nitrogen. This result agrees with the field observations of several workers that irrigation decreases the percentage of nitrogen in plants (Iljin, 1954; El Tomi, 1955; Janes, 1948; McMurtrey, 1947).

The distribution of potassium in various parts of the plant, as affected by soil moisture, needs special comment in view of the fact that, whereas in the whole plant the concentration increases from June to July and falls from July to September, in parts of the plant, viz. the shoot and root, the concentration falls steadily. This implies that during the early part of the season either the potassium is stored in the root and new shoot in excess of immediate metabolic requirements or that it is in special demand at these sites in the summer for metabolic reactions which become less important in the overall economy of the plant later in the season. The figures for concentration of potassium in Table II and for total amounts in Fig. 2 would suggest that by far the heaviest demand for potassium occurs in the leaves, thereby creating a potassium stress in other parts of the plant. Under the "wet" treatment the demand is probably more readily met by absorption and the withdrawal of potassium from the root is therefore not so evident as it is under the "dry" treatment.

With regard to the magnesium content of the leaves of the plant, one point is worthy of further discussion. From Table II it may be seen that, although frequent watering increased the magnesium concentration in the top leaves, it was accompanied by a decrease in the bottom leaves. For the top leaves the positive difference due to treatments was significant ($P < 0.001$) at the July sampling but not in September, and for the bottom leaves the negative difference was significant ($P = 0.001$) again in July but not in September. In September the actual difference between magnesium content of top and bottom leaves under the "wet" treatment was 0.13 per cent. and very highly significant ($P < 0.001$), while under the "dry" treatment the difference was only 0.05 per cent.

These facts are of interest in relation to field observations that the necrosis and premature abscission of basal leaves, which is characteristic of magnesium deficiency, is more prevalent in a wet season. In this experiment the supply of magnesium was

adequate and the basal leaves of the plants did not exhibit symptoms of magnesium deficiency. If, however, under field conditions the supply of magnesium were barely adequate in a dry season, then these results would suggest that in a wet season the higher magnesium stress in the plant brought about by moist soil conditions would lead to a relatively low concentration in the bottom leaves and the consequent development of deficiency symptoms.

To recapitulate briefly, the direct results of this work show that apple plants grow better, and in doing so absorb more of the five major elements, N, P, K, Ca and Mg, when the soil is maintained in a moist condition than when it is allowed to dry out. The rate of uptake of these elements in relation to amount of growth produces concentration changes in the leaves and in the whole plant, according to the treatment. The "wet" treatment compared with the "dry" produced a significant decrease in percentage of nitrogen and significant increases in concentration of potassium and phosphorus. There is a suggestion that moist soil conditions increase the concentration of magnesium in the whole plant.

These results may be compared with the general conclusions of Richards and Wadleigh (1952) who in their review state that "most experimental evidence shows that . . . decreasing soil moisture supply is associated with a definite increase in nitrogen content of the plant tissue, a definite decrease in potassium content, and a variable effect upon the contents of phosphorus, calcium and magnesium". The only real difference of view relates to phosphorus, since not only in this experiment but in others not reported upon here the phosphorus concentration in the leaves was increased by a moist soil. Other authors who support this finding are Williams and Shapter (1955) and Sheets *et al.* (1955).

Gates (1957) suggests that the tendency for water shortage to produce nitrogen-rich plants may result from the effects of moisture stress on phosphorus nutrition, as the phenomenon usually occurs after a succession of moisture shortages. During a single brief period of water shortage he found that the net uptake of nitrogen during wilting was greatly impaired.

SUMMARY.

1. Apple rootstocks M.VII were planted in John Innes compost in 7½-in. pots and, when growing freely, were placed out of doors under a glass canopy. Half of the pots were watered daily ("wet" treatment) and the other half were allowed to dry to incipient wilting point before being watered ("dry" treatment).

2. Some of the plants were harvested after six weeks and the remainder after thirteen weeks, in order to determine the total amounts and concentrations of the elements N, P, K, Ca and Mg in various parts of the plant.

3. Plants under the "wet" treatment grew more vigorously and absorbed larger amounts of all five elements.

4. The "wet" treatment significantly reduced the concentration of nitrogen in the whole plant ($P < 0.001$), while the concentrations of phosphorus and potassium were significantly increased. By the second harvest the "wet" treatment produced an increase in concentration of magnesium which was significant at a low level ($P < 0.05$) but there was no significant effect on calcium.

5. In general the effects of treatments on the concentrations of elements in various parts of the plant were in the same sense as the effects on the whole plant. The significant exception was the effect on the concentration of magnesium in the bottom leaves ($P < 0.001$ in July).

ACKNOWLEDGMENTS.

The author is especially indebted to Mrs. B. M. Showler and Mr. D. A. Payn for assistance in conducting the experiment and recording the data. The chemical analyses were carried out by members of the Plant Analysis Section, East Malling Research Station.

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BOOK REVIEWS

THE WORLD OF THE SOIL. By Sir E. JOHN RUSSELL. (London : Collins, New Naturalist Series. 1957. Pp. 237, illus. Price 25s.)

This is an outstanding addition to the New Naturalist series. No naturalist can afford to ignore the soil. It provides more than half the environment of most of the plant world, while it possesses a vastly complex flora and fauna of its own. There has been a crying need for an up-to-date book on British soils, which could be read with interest and pleasure, not only by the numerous scientists whose work brings them into contact with soils either directly or indirectly, but also by the rapidly increasing body of agriculturists who seek to understand as much as they can of the fundamentals of their craft. Perhaps it is not too much to hope that the enquiring mind of the intelligent layman will lead him to take advantage of the opportunity now offered of reading about this most important of all the raw materials that mankind uses.

In *Soil Conditions and Plant Growth* Sir John presented a monumental work covering most of the main aspects of soil science, or rather the many sciences that meet together in attempting to solve the problems of the soil. But that is a highly technical book for the specialist. Now, at a time of life when the majority of men would have considered themselves entitled to a well-earned retirement, he continues to make stimulating contributions to the literature of the subject. In this latest one he has covered a wide field with remarkable skill and clarity of expression. He makes it quite plain from the outset that he will avoid over-simplification, which can only prove misleading in a subject so complex as the soil, while at the same time keeping technical terms to a minimum. He has achieved much by the use of well-chosen simile and has enlivened his account by numerous interesting examples. Not the least instructive of these are the explanations he gives of how research workers have, on occasion, narrowly missed making important discoveries from their experiments.

A chemist by training, he quite naturally begins with an account of the chemistry and physics of the soil but he then devotes a considerably greater space to its inhabitants. He points out that an apparently lifeless clod of soil is only about half solid matter, the rest being spaces full of air and water, the home of countless micro-flora and fauna. Much of soil science is, in fact, the study of the minutely small.

Throughout this and the next section, which is devoted to man's attempts to control the soil, Sir John quotes freely from experiments carried out at Rothamsted, linking the researches of the laboratory and the field plot repeatedly with the experiences of the farmer and gardener. His brief final chapter on what we obtain from our soil gives a picture of a national asset which cannot lightly be disregarded.

There is, however, one notable omission for a book on the soil. Of thirty-seven excellent plates only one is of a soil, and that not a very inspiring one. Nowadays there are excellent coloured photographs available which would have helped the reader to realize that soils exist as individuals, just as do the different species of plants, and would have encouraged him to go out and look for them. Their very unfamiliarity and inaccessibility make all the greater the need to present them, and the relationship

they bear to one another, as clearly as possible to those who have not looked closely at soils where they exist—in the field. Even though much of the study of the soil demands well-equipped laboratories, soil science still has a need of acutely observant naturalists as well.

This is a book packed with absorbing fact and it is not the fault of its brilliant author that many paragraphs pose as many questions as they answer. Soils are tantalizingly difficult to study and in most of its aspects the work has little more than begun. It is a book which will provide food for thought to scientific and lay readers alike ; some may be fired by the bibliography to further reading.

B.S.F.

FLOWERING TREES IN INDIA. By M. S. RANDHAWA. (New Delhi : Indian Council of Agricultural Research. 1957. Pp. 209, illus. Price Rs. 15.)

This is a book written by an enthusiastic lover of trees, partly to inspire similar feelings in others, but also to give practical advice on the choice of species for different sites and purposes as part of an Indian Government scheme to stimulate tree-planting. This dual purpose is evident from such chapter headings as "The quest of the beautiful tree", "The pageant of the seasons" and "Trees in modern Indian art" contrasting with others like "Avenues for national and state highways" and "The tree-planting plan of New Delhi".

The author's approach is that of bioaesthetics, in which, he states, "science and art are welded together and ideas of truth and beauty coincide". The book could be described as more artistic than scientific. This is not to belittle its practical value to the horticulturist and landscape gardener in the tropics, but to do justice to the eloquence of the prose and the beautiful reproduction in colour of thirty-eight paintings of trees in bloom.

Many tropical and subtropical countries are now paying increased attention to tree-planting in towns and college grounds, both for the shade and the scenic value of trees. This book will be valuable to those responsible for planning this long-term improvement and will be enjoyed by all who regard trees as the most pleasing adornment of the landscape.

A.F.P.

ATOMIC ENERGY IN AGRICULTURE. By WILLIAM E. DICK. (London : Butterworths Scientific Publications. 1957. Pp. 150, illus. Price 15s.)

This book has appeared in the "Atoms for Peace" series and is well described by its title. The reader is assumed to possess a wide knowledge of science that does not necessarily go very deep ; neutrons, cytoplasm, roentgens, hexose sugars, etc., are all alluded to with little explanation. Accordingly, the book is not one for the narrow specialist seeking more specialized knowledge, but it will be read with enjoyment by many who want to know what is going on in the world and who have the width of background to follow it. It is informative, intelligible, and entertaining. Thus, the account of the eradication of screw-worm from Curacao by the introduction of irradiated males, leading to infertility of the eggs, is full of interest though the outline of the story is well known.

Horticulturists will be glad to know that the word "agriculture" is used in no narrow sense ; indeed, rather a lot is said about fruit, while flowers, forest trees, and even stored meat, all receive attention.

S.C.P.

A MORPHOLOGICAL CLASSIFICATION OF RASPBERRY VARIETIES. By J. A. LEEMANS and E. T. NANNENGA. (Instituut voor de Veredeling van Tuinbouwgewassen, Wageningen. 1957. Pp. 140, illus. Price H. fl. 25.)

Fifty-three raspberry varieties are described in this book, which is written in English and is copiously illustrated with excellent photographs. The size, $7\frac{3}{4} \times 10\frac{1}{2}$ in. makes it rather difficult to handle in the field, where its paper cover would also be a disadvantage. This seems a pity, because the book could easily have been made smaller by reducing the background in the photographs and by using more fully the space available for print. The writers are to be congratulated on having so clearly defined and illustrated the various diagnostic characters they use in delineating the varieties. The varietal descriptions, in general, seem excellent and, although one would not always agree with the assessment of such characters as spininess, it is appreciated that considerable phenotypic variation occurs in raspberry varieties in different localities.

A key to the identification of commercial varieties of any crop is almost invariably extremely difficult to compose, largely because varieties often differ from each other in a number of small and ill-defined characters, especially when several types have been bred from a common stock. The raspberry is no exception to this, and the reviewer found certain difficulties in using the "Identification Key". In item 12 in the key it is not clear whether "very late" refers to the general fruiting season or to the autumn crop. Moreover, no explanation is given for the inclusion of occasional numbers in brackets in the key. The authors, however, emphasize that the key is to be regarded as an adjunct to the varietal descriptions rather than as a means by itself of certain identification.

The reviewer noted many spelling mistakes ; such errors as Madewaska as the heading for the description of the variety Madawaska could easily have been avoided. These criticisms are, however, relatively minor, and the book provides an excellent and much needed descriptive account of raspberry varieties and their synonymy.

R.L.K.

CONTROL OF THE PLANT ENVIRONMENT. Edited by J. P. HUDSON. (London : Butterworths Scientific Publications. New York : Academic Press Inc. 1957. Pp. 240, illus. Price 42s.)

"Give us the tools and we will finish the job" made a fine sounding party cry ; "Give us the tools and we'll be able to start the jobs" is a closer approach to many research workers' heart cry. This volume, the outcome of the fourth of the valuable series of Easter Schools in Agricultural Science at Nottingham University, pools the experience gained by some forty-seven workers at twenty-two research centres and university departments with different environmental "tools", ranging from simple windbreaks to complex phytotrons. Such a wealth of contributors naturally produced some conflict of opinion ; fortunately for those who did not attend and for posterity this is publicized in the discussions following each contributor's paper.

The book is divided roughly into two halves : discussion of the effects of environment, and descriptions of existing methods of controlling it for experimental work and of measuring its components. The title might thus have been " The plant environment : its effects and control ". For full accounts of both of these, reference must be made to a very wide literature. Unfortunately, it has apparently been impossible to print the titles of the many references cited. Part of the value of the book lies in drawing attention to them.

Controlled environments are not intended to simulate natural conditions, but to provide uniform, reproducible conditions in which the individual factors can be varied. If unwanted variation within the environment is randomly distributed the number of plants under experiment can be minimized and still give reliable results. Unfortunately, in many existing installations there are marked gradients in one or more components of the environment. Straining at perfection in control may risk breaking one's neck ; a stepwise policy of improvement is often more practicable. For short-term experiments close control may be essential, for long-term growth and developmental studies partial control may be adequate.

Caution has to be observed when close analysis of environment and growth is undertaken. The factors under investigation, e.g. temperature, may differ close to the surface or in the tissues of the plant from those measured as constituting the environment.

The need for collaboration between geneticists and plant physiologists in relation to the environment is stressed. This applies equally between these specialists and plant pathologists. One requirement, rarely met, is that of providing adequate technical assistants to service the equipment, and another is provision of sufficient recorders and computers to collect and analyse the data. Emphasis should once again be laid on the fact that obtaining data on plant growth is a very much more laborious process than designing or operating controls for the environment or of measuring the different factors comprising it. It is not surprising that knowledge of relationships between the plant and its environment is still scanty.

Some of the economic aspects and general policy on allocation of environmental control installations are discussed. The danger of providing over-elaborate installations leading to loss of freedom in programming is pointed out. An equal weakness lies in the official lack of appreciation of the value of controlled environment in shortening and generally facilitating experimental work. It has been the reviewer's sad experience to see a £10,000 (pre-war) installation abandoned.

Professor Hudson is to be congratulated on the provision of a useful preface and on the skilful editing of the mass of data, and particularly on its early publication.

How far has the meeting achieved its objects ? This will be for the future to tell. If it serves to stimulate laggards, to correct errors of technique in existing installations and to prevent their repetition in new ones, it will have been valuable. If in addition it prevents the abuse of expensive equipment by under-employment or misapplication on projects soluble by simpler methods, it will have saved the cost of the meeting and many times the price of the book.

E.R.L.

THE FRUIT YEAR BOOK 1958. (London : The Royal Horticultural Society. 1957. Pp. 176, illus. Price 10s.)

After an interval of two years, *The Fruit Year Book* (No. 10) has arrived, just

at the right time of year when the gardener can sit by his fireside with a clear conscience and read it.

This year there seems more for the amateur gardener himself than in some previous numbers, while even those whose only contact with the garden is a visit to Chelsea or the R.H.S. Fruit Show in the autumn will find articles on fruit books and on the history of apples and gooseberries that they will enjoy. After reading these they will rightly ignore the horrible attempts to produce new varieties of apples by bombarding trees with nuclear particles from an atomic energy reactor!

This review cannot appear in time for Christmas 1957 but there will be no Fruit Year Book in 1958, so nobody need hesitate to give it to their fruit-loving friends next year.

T.N.H.

THE MANGO. By S. R. GANGOLLY, R. SINGH, S. L. KATYAL and D. SINGH. (New Delhi: Indian Council of Agricultural Research. 1957. Pp. 530, illus. Price \$12 or 85s.)

This exceptionally well produced and authoritative book results from studies sponsored in 1948 by the Indian Council of Agricultural Research. Its subject is India's foremost fruit and one of the great crops of the world. Once again one is struck by the almost fabulous nature of the mango—a tree that is as much a feature of India's culture and folklore as it is of India's countryside. Its economic importance is vast, occupying as it does some 1½ million acres in India alone, and to other countries throughout the tropics its present or potential importance is as great.

Yet the total of scientific knowledge about the mango is far from commensurate. Possibly the few workers in tropical countries have had more pressing tasks or have been overwhelmed by the confusing multiplicity of varieties and of vernacular names and synonyms. In this respect this volume makes immediate appeal. Of the 1,400 or so Indian varieties, only 210 have been selected and described so that one recognizes a wholesome and welcome restraint. And of these only a few are fully commended for quality; indeed only twenty-six or so are rated as "very good" and only six better still.

The book first provides a useful section on the botany of the tree—a brief *hors-d'oeuvre* leading up to the main dish which consists of 210 page-length descriptions of varieties, each accompanied by a superb coloured photograph of the fruit—but not, alas, including the leaves and blossoms. These photographs are the outstanding feature of the book. The descriptions are clear and adequate and such technical terms as are used are clearly defined and illustrated in the preliminary pages. There is no attempt to provide an artificial key.

The closing sections concern the cultivation of the tree and its pests and diseases. There is little of substance to record and there is clearly a great need for more scientific work on the mango. This book will greatly assist future workers by providing a clear statement of what is already known and, since selection and breeding are the major tasks ahead, by guiding workers through the labyrinth of so-called varieties. It can be confidently recommended to all who are interested in tropical horticulture and equally to those who live in India and wish to enjoy a closer gustatory knowledge of the best of tropical fruits.

G.E.T.

NOTICE TO CONTRIBUTORS

1. All **manuscripts** should be in double-spaced typewriting, with a good margin, and should be addressed to the Editor, East Malling Research Station, near Maidstone, Kent, England. Papers must be written concisely. Historical reviews should be as short as possible and only such references to literature as bear directly on the subject should be included. Tables and illustrations, if any, must be only such as are absolutely essential for clear presentation.

2. Authors of papers containing extensive **numerical observations** should consult the recommendations of the British Association Committee on Biological Measurements, 1927, obtainable from Burlington House, London, W.1, price 6d. Arrangements have been made whereby original data too extensive for complete publication may be deposited at the British Museum (Natural History), London, S.W.7, or with the Royal Society of Edinburgh, 22 George Street, and thus be available for consultation by other workers. Full bibliographical reference to the publication in which the results are summarized must be supplied with the data.

3. Each paper must conclude with a concise and critically correct **summary** of its actual content. It should contain any new or verified constants as well as any other critical data of permanent value but not tables or graphs. Any organism mentioned should be given its scientific name.

4. Where a paper is of a highly technical nature it should be preceded by a brief **synopsis**, in which its contents are simply and clearly stated for the benefit of non-technical readers.

5. **References to literature** may be by numbers (in brackets) in the text corresponding to a numbered list at the end of the paper or by the Harvard system (author's name and date of publication). By either method, the papers cited should be listed alphabetically according to authors' names, followed by the date of publication. The title of the paper should next be given in full, followed by contracted, but strictly intelligible, title of source of publication, the volume and page numbers. Authors are responsible for the accuracy of their lists of references and should check them carefully in both typescript and proof.

6. The **scientific names** given in the "List of Common British Plant Diseases", published by the British Mycological Society (Cambridge University Press, 1944, revised edition in the press) and "Common Names of British Insect and other Pests", published for the Association of Applied Biologists (1947 and 1952) must be employed.

7. Authors in this country will be supplied with slip and page **proofs** of their papers; these they should correct with care immediately on receipt and return without delay, together with the original manuscript. Typographical errors, if any, should be corrected; small verbal alterations are permissible, but substantial changes may not be made. Overseas authors should be willing to accede to editorial treatment of their contributions, if necessary, limited to methods of presentation, and leave proof correction to the Editors.

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10. The suggested **abbreviation** for the title of this publication is *J. hort. Sci.*

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HORTICULTURAL ABSTRACTS

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